Department of Energy
Richland Operations Office
P.O. Box 550
Richland, Washington 99352

JAN 2 6 1998

Ms. Donna L. Powaukee
Nez Perce Tribe
P.O. Box 365
Lapwai, ID 83540-0365

Dear Ms. Powaukee:

REVIEW AND COMMENT ON NEEDS AND REQUIREMENTS FOR CONSOLIDATION OF SITE-WIDE GROUNDWATER MODELING AT THE HANFORD SITE

In May 1996, at the Hanford Advisory Board (HAB) workshop there was a recommendation to the U.S. Department of Energy, Richland Operations Office (RL) to develop a site-wide consensus groundwater model for the Hanford Site. RL's Site Management Board directed the Environmental Restoration Program to lead the effort to provide the Hanford Site a Site-Wide Consolidation Groundwater Model. In a RL letter to the regulators, stakeholders, and tribes, dated July 28, 1997, RL made a commitment to initiate the site-wide groundwater model consolidation task.

As a result of a number of meetings with RL, contractors, regulators, tribes, and HAB in review of past modeling work the "Need and Requirements for Consolidation of the Site-Wide Groundwater Modeling at the Hanford Site" (Attachment) document has been developed.

Please review and provide comments by March 3, 1998. If you have any questions, please contact me on (509)373-9626.
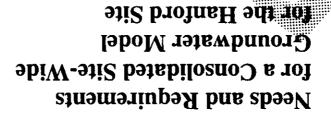
Sincerely,

R. A. Hildebrand

R. D. Hildebrand, Project Manager
Groundwater Project

GWP:RDH

Attachment

cc w/attach:
S. Sobcyzk, NPT

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United States
Department of Energy
P.O. Box 550
Richland, Washington 99352

DRAFT

December 1997

Needs and Requirements
for a Consolidated Site-Wide
Groundwater Model
for the Hanford Site

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Executive Summary

In response to both internal and external recommendations, DOE/RL initiated a site-wide model consolidation process, which is to include the participation of all affected Hanford programs, to eliminate redundancies and promote consistency in groundwater analyses produced for Hanford programs. The purpose of the model consolidation is to establish a site-wide modeling process to foster 1) consistent assumptions in applications across programs, 2) model enhancements based on new data/information and improved technical capabilities, and 3) model flexibility to address new program needs and decisions. As an initial step in FY 1998, the consolidation process is to provide a current Hanford site-wide groundwater model based on a consensus hydrogeologic conceptual model, a consolidated database, and the selection of computer codes to implement the numerical model developed based on the consensus conceptual model that will meet near-term and long-term needs and requirements of internal and external Hanford site stakeholders.

At Hanford, several groundwater modeling programs have developed among the three major contractors since the Hanford mission changed from special nuclear materials production to environmental restoration. The Project Hanford Management Contractor (PHMC) presently maintains a vadose zone and groundwater modeling capability in support of active and planned disposals in the 200 Areas and operational issues at the site. Bechtel Hanford, Inc. (BHI) presently maintains a site-wide groundwater model in support of past-practice operable unit investigations and cleanup activities. Pacific Northwest National Laboratory (PNNL) presently maintains groundwater modeling capabilities for the site in support of the site-wide groundwater monitoring program, and vadose-zone modeling capabilities for a variety of site and national programs.

This report provides an initial assessment of the needs and requirements necessary to move forward in the model consolidation process. The recommended needs and requirements were largely derived from a review of recent, current and planned groundwater modeling activities provided by representatives of major RL programs including Environmental Restoration, Waste Management, and Tank Waste Remediation System programs. Input was also provided by involved Hanford Site contractor representatives from BHI, CH2M-Hill, PNNL, Fluor Daniel Northwest (FDNW), Waste Management Federal Services Hanford (WMFSH), Lockheed Martin Hanford Company (LMHC), and Jacobs Engineering Group, Inc. (JEGI).

Based on a review of current and planned groundwater modeling activities at the site, the following needs and requirements have been identified for the consolidated site-wide groundwater model objectives, the conceptual model and associated database, and the computer code needed for implementation of the numerical model.

Consolidated Model Objectives: The consolidated site-wide groundwater model should be capable of being used to meet a variety of Hanford Site project objectives including the following:

- preliminary screening of sites for locating waste disposal facilities

- site performance assessments of proposed waste disposal facilities

- assessment of environmental impacts involving the prediction of contaminant transport and dose modeling for site-wide and local assessments

- design and evaluation of groundwater remediation strategies including natural attenuation, hydraulic control/containment, and contaminant removal/cleanup.

- design and evaluation of site monitoring networks to predict fate and transport of existing and emerging contaminant plumes, transient hydraulic behavior of the water table and unconfined aquifer system in response to changing waste management practices, environmental restoration alternatives, or waste facilities end states, and performance of groundwater remediation alternatives

- risk assessments

Consolidated Model Conceptual Model and Database Needs and Requirements: The major needs and requirements for a consolidated site-wide groundwater modeling program with respect to the conceptual model are as follows

- A common site-wide modeling database based on a geographic information system and containing all the information necessary to develop parameter estimates for a model should be used in all modeling applications.

- This modeling database should be based on a consensus interpretation of the available data.

- The database and data interpretations should be updated as new data, on both the local and regional scale, become available. These changes in parameter databases should be maintained using appropriate configuration control procedures to establish the pedigree of all changes

- Any conceptual models that make additional simplifications to the site-wide modeling database should include adequate documentation to demonstrate consistency. Such documentation may include a list of assumptions made, their justification, and comparisons with simulation results based on the most complete and complex conceptual model.

Consolidated Model Computer Code Requirements: The code selected for implementation of the consolidated site-wide groundwater model should provide the following technical capabilities and characteristics. The code should be capable of:

- simulating two- and three-dimensional saturated, unconfined and confined flow of constant density water in an isothermal setting for either steady state or transient flow conditions in order to be able to represent both current as well as expected future Hanford Site states. For certain modeling applications such as the simulation of remediation options for the carbon tetrachloride plume in the 200 areas or the evaluation of innovative in-situ treatment technologies such as in-situ REDOX treatment methodologies, capabilities to simulate the effects of variable density would be desirable

- accommodating the spatial variation of hydraulic parameters (hydraulic conductivity, transmissivity, specific storage, storage coefficient, etc.) in three dimensions as well as the three-dimensional geometry of the major hydrogeologic units. The code should also allow anisotropic hydraulic conductivity values

- simulating flow and contaminant transport in unconfined and confined portions of the Hanford aquifer systems

- simulating flow conditions at the scale of the entire Hanford Site with robust sub-modeling capability to facilitate the systematic transfer of attributes of the flow and contaminant transport model derived from the site-wide model for use in local-scale modeling assessment as appropriate

- effectively simulating flow on a variety of time scales ranging from a few years to 10,000 years at both the scale of the entire Hanford Site and at the local scale

- simulating contaminant fluxes in two- and three-dimensions as a function of driving hydrologic processes and mass transport phenomena, including advection, hydrodynamic dispersion, molecular diffusion, and adsorption

- representing geochemical retardation using a linear equilibrium adsorption model where the distribution coefficient (K_d) depends only on the contaminant and on spatial position

- treating the effects of radioactive decay. Another desirable but not required feature would include the capability to analyze the effects of complex decay chains (for example, the decay of uranium)

- efficiently simulating flow conditions only, contaminant transport based on previously simulated flow conditions, or combined flow and contaminant transport

- efficiently performing streamline (for steady-state conditions) and pathline (e.g. for transient conditions) analyses in two- and three-dimensions

- Incorporating time-dependent and spatially varying boundary conditions. The code should be capable of simulating homogeneous and non-homogeneous Dirichlet (constant head/concentration) and Neuman (constant flux) boundary conditions. The selected code should also have a prescribed approach for incorporation of time- and space-dependent sources and sinks of water and contaminant

Administrative requirements for the selected code include the following:

- pre- and post-processing modules that allow the user to readily set up problems and to understand results. In particular, the code should have the capability to provide outputs that can readily used by its own pre- and post-processors or other available software to graphically display the numerical grid discretization along with zone identifiers, contaminant and water fluxes across selected boundaries and regions in the modeling domain, and contours, spatial cross sections, and time histories of contaminant concentrations

- An effective model interface to a GIS such as the proposed site-wide modeling database to allow the efficient specification of hydraulic properties, boundary and initial conditions, and sources and sinks

- evidence of reliability including adequate documentation, verification against a set of test problems relevant to Hanford groundwater conditions, and a body of model applications that can demonstrate its technical, regulatory, and public acceptance

- availability for both internal contractor and external stakeholder use at a reasonable cost

- the most recent version of the code should be available, preferably the last one that has been fully tested. For codes that are well established, the use of a well-tested version may outweigh the use of a newer, but less tested version. The software should be maintained under a quality control program that documents modifications.

- availability of a variety of computational algorithms and solvers to facilitate the efficient simulation of a wide variety of flow and contaminant transport problems and capabilities to run on a variety of computational workstations and platforms including UNIX-based workstations.

- proprietary codes will be considered if they provide an advantage over public domain codes and only if the author(s)/custodian(s) allow inspection and verification of the source code by DOE and its contractors. These inspections and/or verification reviews may be required to assist DOE to rectify problems encountered in application of the code or in working with the code author(s) to develop technical approaches for required code enhancements.

- the selected code should be sufficiently well documented and well supported by the code developer to allow for rectification of technical difficulties that arise in its application to Hanford specific applications.

Other Needs and Requirements: Other needs and requirements that must be considered in a site-wide model consolidation include the following:

- development of a process to foster greater consistency in applications of groundwater models by various on-site programs

- site commitment for long-term maintenance and care of site-wide modeling capabilities.

Acknowledgments

Tank Waste Remediation System Program

Department of Energy, Richland Operations Office Representatives

Robert Lober, TWRS EIS and Hanford Tank Initiative
David Shafer, TWRS Vadose Zone Program
Phil Lamont, TWRS LAW Disposal Facility

Site Contractor Representatives

Phil Rogers, JEG, TWRS EIS and Hanford Tank Initiative
Fred Mann, FDNW, Performance Assessment of the TWRS LAW Disposal Facility

The authors also wish to acknowledge input provided by several individuals involved in staff consultations of this effort with U. S. Environmental Protection Agency, the Washington State Department of Ecology, the Nez Pierce Indian Nation, the Yakama Indian Nation, and the Hanford Advisory Board. Representatives of these organizations are as follows:

U. S. Environmental Protection Agency,

Doug Sherwood
Larry Gadbois

Washington State Department of Ecology

Dib Goswami
Shri Monan

Nez Pierce Indian Nation

Stan Sobcyzk

Yakama Indian Nation

Lionel Nicolleti
Barbara Harper
Wade Riggesby

The Hanford Advisory Board

Members of the Environmental Restoration Subcommittee chaired by Madeline Brown, FDHC

Project staff were unable to meet with representatives of the Confederated Tribes of the Umatilla Indian Nation prior to preparation of this draft report. However, a copy of this draft will be transmitted to Confederated Tribes of the Umatilla Indian Nation for technical review and comment.

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1.0 Introduction

In response to both internal and external recommendations, DOE/RL initiated a site-wide model consolidation process, which included the participation of all affected Hanford programs. This process will eliminate redundancies and promote consistency in groundwater analyses produced for Hanford programs. The DOE/RL Site Management Board (SMB) directed the Environmental Restoration Program to lead the effort. On Sept. 5, 1996, John Wagoner issued an RL Letter of Instruction to affected RL Programs, and Site Contractors that "...with RL and contractor customers, tribal and stakeholder participation, PNNL will develop and maintain a predictive Hanford standard groundwater model..." In a letter to regulators and stakeholders dated July 28, 1997, RL also made a commitment to initiate the model consolidation process in FY 1998.

At Hanford, several groundwater modeling programs have developed among the three major contractors since the Hanford mission has changed from special nuclear materials production to environmental restoration. The Project Hanford Management Contractor (PHMC) presently maintains a vadose-zone and groundwater modeling capability in support of active and planned disposals in the 200 Areas and operational issues at the Site. Bechtel Hanford, Inc., (BHI) presently maintains a site-wide groundwater model in support of past-practice operable unit investigations and cleanup activities. Pacific Northwest National Laboratory, (PNNL) presently maintains groundwater modeling capabilities for the site in support of the site-wide groundwater monitoring program, and vadose-zone modeling capabilities for a variety of site and national programs.

The purpose of the model consolidation is to establish a site-wide modeling process to foster 1) consistency in assumptions in applications across programs, 2) model enhancements based on new data/information and improved technical capabilities, and 3) model flexibility to meet and support new program needs and decisions. As an initial step in FY 1998, the consolidation process is to provide a current site-wide groundwater model of the site based on a consensus hydrogeologic conceptual model, database, and numerical model that will meet near-term and long-term needs and requirements of internal and external Hanford site stakeholders.

In FY 1998, the scope of the model consolidation is to 1) establish the needs and requirements of a Hanford site-wide groundwater model, 2) evaluate current interpretations, data, models, and codes, 3) make recommendations for consolidation, 4) conduct review of recommendations, 5) document review and recommendations, and 6) initiate implementation of the recommendations.

Current plans also call for completing implementation of the site-wide groundwater model and development of a multi-year program plan in FY 1999 to provide continued support for the site-wide model from the years 2000 to 2005.

1.1 Approach for Model Consolidation

On October 27, 1997, RL initiated the model consolidation process with representatives of affected RL programs and contractor personnel. An overview of the model consolidation process included descriptions of the four major tasks:

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- development of site-wide modeling needs and requirements

- technical evaluation of site-wide conceptual and numerical models

- recommendations for a consensus site-wide conceptual and numerical model and computer code(s) to implement the consensus numerical model

- implementation of the recommendations.

To facilitate the development of the needs and requirements summarized in this report, program representatives were asked to provide an overview of current and planned model activities including identification of supporting planning and technical documents. The documents identified provide the basis for summaries of current and planned groundwater modeling activities described in section 2 of this report.

RL also consulted with representatives of the U. S. Environmental Protection Agency (EPA), Washington State Department of Ecology, the Hanford Advisory Board, and affected tribal nations that included the Nez Pierce Tribe, and the Yakama Tribal Nation about the model consolidation process. Although RL was unable to meet with representatives of the Confederated Tribes of the Umatilla Indian Reservation prior to preparation of this draft report, RL is in the process of arranging a consultation about the model consolidation process and a copy of this draft report will be transmitted to them for technical review and comment.

To facilitate the technical evaluation of site-wide conceptual and numerical models and the implementation of the selected computer code(s), RL intends to conduct a series of workshops with technical points of contact from internal program and external regulatory agencies, tribal nations, and interested public stakeholder groups. The purpose of the workshops will be to review and identify key differences in assumptions and approaches in

- current site-wide model uses, including temporal and spatial scales evaluated, scenarios addressed, contaminants of concern assessed, etc.

- current site-wide hydrogeologic and geochemical interpretations and associated databases

- existing modeling implementations and assumptions including the purpose and scope of the implementations, the key assumptions, the limitations, etc.

Following the initial review of site conceptual models and numerical model applications and the computer codes currently in use, RL intends to have technical subject area experts meet to evaluate key areas of differences and to present recommendations for resolution to the larger group of technical points of contact (POCs) for review and comment. PNNL will work closely with the POC group to collate and document final recommendations for site-wide model consolidation. The scope of recommendations will include discussions on the following topics:

- current site hydrogeologic interpretations

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- current site hydrologic conceptual model for groundwater flow and contaminant transport
- selected computer codes and related software.
- development of parameter databases and their implementation of numerical models
- a process for ensuring consistency in modeling applications performed on site
- a process for long-term maintenance and care of 1) recommended hydrogeologic and hydrologic databases, 2) model parameter databases, and 3) site-wide model(s) and computer codes.

The developed recommendations will be presented for review by an external peer panel (early May 1998) and to internal and external stakeholders by mid to the end of May 1998. Comments and suggestions solicited during the review will be evaluated and to the extent possible will be incorporated into an RL document titled, *Requirements, Review, and Recommendations for a Consolidated Site-Wide Groundwater Model for the Hanford Site*, by August 30, 1998.

Following review of the recommendations for model consolidation in the May 1998 time frame, RL will initiate the implementation of the recommendations. The proposed date for completing implementation of the consolidated site-wide model, including the development, calibration, application, and documentation is currently planned for July 30, 1999. However, this proposed date may need to be revised based on the recommendations and resulting scope.

1.2   Purpose and Scope of Report

The purpose of this report is to document the initial assessment of needs and requirements necessary for site-wide consolidation of groundwater modeling. These needs and requirements are based in part on an initial review of current and future groundwater modeling activities being planned by the Environmental Restoration, Waste Management, and Tank Waste Remediation programs at the Hanford Site. The needs and requirement also reflect input collected from external stakeholders including U.S. EPA, Washington State Department of Ecology, the Hanford Advisory Board, and two of the affected tribal nations (the Nez Pierce Tribal Nation and the Yakama Tribal Nation). Representatives of the Confederated Tribes of the Umatilla Indian Reservation will be consulted and asked to participate in the model consolidation process.

The remainder of the report is separated into two sections organized in the following manner:

- Section 2.0 provides summaries of current and planned groundwater modeling activities of major program areas at the Hanford Site, including the Environmental Restoration, Waste Management, and Tank Waste Remediation System Programs.

- Section 3.0 provides a summary of site-wide groundwater needs and requirements necessary to achieve the objectives of the model consolidation process

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2.0 Current Groundwater Modeling Activities

The following is a brief review of recent and current groundwater modeling activities that have been undertaken by the major programs at the Hanford Site. The information presented is organized by major program areas (i.e., Environmental Restoration, Waste Management and Tank Waste Remediation System programs) and was largely derived from meetings with representatives of RL programs and site contractor personnel and review of related key technical documents. In performing this review, a conscience effort was made to limit groundwater modeling activities to those completed within the last three years (i.e., since 1994). Thus, the review of past groundwater modeling, for the most part, is focused on those modeling activities completed since 1994.

2.1 Key Projects in the Environmental Restoration Program

Following is a review of project activities that have used groundwater modeling to support major objectives for the Environmental Restoration Program. These summaries reflect information provided by RL technical project managers and contractor personnel from BHl and PNNL. The modeling activities summarized include those associated with the following key activities within the ER program.

- Development of the Hanford Site-Wide Groundwater Remediation Strategy
- Remedial investigation / feasibility study of the Environmental Remediation Disposal Facility
- Design of Interim remedial measures in the 100 and 200 Areas
- Assessments being done under the Hanford Groundwater Project including:
  - Monitoring network assessments
  - Impacts on Drinking Water Systems and Groundwater Uses from existing contaminant plume transport
- Composite Analysis being performed in response to the Defense Nuclear Facility Safety Board recommendation 94-2
- Hanford Remedial Action and Comprehensive Land Use Environmental Impact Statement

The following summary focuses on groundwater modeling being done to support evaluation of groundwater impacts and does not specifically discuss risk assessment methodologies being used to support cleanup of soil contamination at many CERCLA sites in the 100 and 200 areas. Much of this type of remediation work at the Hanford Site has been supported with the implementation of a dose assessment methodology recommended for deriving site-specific soil remediation guidelines called RESRAD developed at Argonne National Laboratory (Yu et al. 1993).

2.1.1 Hanford Site-Wide Groundwater Remediation Strategy

Site-wide groundwater modeling has been performed to assess groundwater remediation alternatives, to support planning and implementation of remediation alternatives, to support risk assessments, and to evaluate the impact of changes in the groundwater flow field. This particular modeling activity is summarized in detail in Law et al. (1996) and Chiaramonte et al. (1996).

Geologic and hydrogeologic conceptual models were based primarily on a synthesis of data and information presented in previous studies. The conceptual model involved defining properties and spatial distribution of the major geologic units in the Ringold and Hanford formations and defining the surface of the basalt bedrock.

Recharge to and discharge from the unconfined aquifer were based on previous studies. Recharge was assumed to occur from the Cold Creek and Dry Creek basins and not from the surface or from the confined aquifer. Discharge to the Columbia River was modeled. Artificial recharge from site operations was based on available reports.

Hydraulic conductivity data from aquifer tests reported in previous studies were used. Scaling from the pump test point measurements to the areal values consistent with the groundwater numerical model was done with the EarthVision software.

Twelve numerical codes were evaluated for use in the site-wide groundwater modeling. The VAM3DCG code was selected because 1) it uses a robust set of solution algorithms, 2) the original developer is a well-known expert and was available for technical support, 3) the code efficiently simulates unconfined aquifer conditions, 4) the code allows the use of transitional elements to refine the numerical grid over specific areas, and 5) the code can be used to model unsaturated zone problems.

Grid sizes were chosen to balance resolution (accuracy) and required computational time. The initial grid chosen to model groundwater flow and tritium transport used uniform 600 m by 600 m elements (18,277 nodes) and required about five hours of computational time for a 200-year simulation (using an SGI Indigo 6000 computer). This grid proved to be too coarse to model smaller contaminant plumes and the grid was refined in the 200 areas to have 150 m by 150 m elements. All elements in the horizontal plane were rectangular (or square). 200-year simulations with the fine grid (50,848 nodes) required approximately 23 hours.

Six elements were used in the vertical dimension; three for the pre-Missoula/Hanford formation and three for the Ringold formation. Element size varied from 0.5 m to 20 m. The vertical elements were deformed (non-rectangular) to match the contours of the hydrogeologic formations. Hydraulic properties within each of the two formations were vertically homogeneous.

Hydraulic conductivity and porosity varied spatially in the horizontal direction. Initial assignment of conductivity to elements was based on observed aquifer test data. Conductivity was isotropic in the horizontal direction. Vertical hydraulic conductivities were set to one-tenth the horizontal value for each element.

Calibration was carried out by adjusting assigned hydraulic conductivities, solving for the steady-state flow field, and comparing the model results to the average water level measurements from 1976-1979. Transient flow simulations of 14 years were also carried out during the calibration, with comparisons of the hydraulic head field during 1988 and 1993 also used to evaluate the numerical model. Finally, a simulation of tritium transport was carried out for the same 14-year period to further evaluate the calibrated model. Tritium concentrations from 1979 were used as the initial condition The mean residual was calculated for the calibrated model using water level measurements at 124 wells.

The calibrated groundwater model was used to predict water table elevations and contaminant transport for several key contaminant plumes (tritium, iodine-129, uranium,

technetium-99, nitrate, carbon tetrachloride, trichloroethylene, and chloroform) for 200 years using 1995 data as the initial condition. Initial sources in the 100 and 200 areas were modeled. The only sources of future releases of contaminants considered during the simulations were for tritium, which considered releases from the Effluent Treatment Facility (ETF), and for carbon tetrachloride, which considered releases from the 216-Z-9 trench. Limited sensitivity analyses were carried out to provide some estimate of critical parameters and the effect of uncertainties. For those contaminants that contribute to risk, an estimate of cumulative risk was made using the industrial and residential scenarios defined in HSRAM (DOE/RL, 1995d).

2.1.2 Environmental Restoration Disposal Facility

A remedial investigation/feasibility study (RI/FS), described in DOE/RL (1994b), was completed to examine the impacts of construction and operation of the Environmental Restoration Disposal Facility (ERDF) located in the south-central part of the 200 Area plateau. The purpose of the RI/FS was to support the goals of the Tri-Party Agreement for the removal of contaminants from portions of the Hanford Site (including near the Columbia River) in a timely manner to allow those remediated portions of the site to be released for other productive uses.

The ERDF was proposed as the receiving facility for wastes generated by remediation of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) past practice units at the Hanford Site. This disposal facility is expected to receive only remediation waste which are expected to consist of hazardous/dangerous wastes, polychlorinated biphenyl (PCB) waste, asbestos waste, radioactive waste, and mixed waste (containing both hazardous/dangerous and radioactive waste). A large portion of the waste in the ERDF are expected to originate from areas along the Columbia River where operable unit records of decision (RODs) are expected to require excavation and removal of large volumes of remediation-generated wastes to the ERDF.

As part of the RI/FS, a fate and transport model was developed to predict groundwater concentrations at the ERDF boundary. Model predicted concentrations were compared to 1) Hanford site background concentrations to identify contaminants that would exceed background and 2) were also compared to risk-based *de minimis* concentrations to develop a list of contaminants of potential concern.

The time frame of concern was 10,000 years, so a 10,000-year travel time constraint was also used as a criterion for identifying key groundwater contaminants. Thus, some contaminants having a travel time in excess of 10,000 years were not considered key groundwater contaminants.

This analysis used a fate and transport spreadsheet model that was developed to represent hydrogeological conditions of the ERDF site, the physical and chemical properties of the waste form, and the fate and transport properties of each contaminant constituent. The estimation of these parameters relied first on the ERDF-specific information and then on Hanford Site background information, when available. Saturated zone parameters included 1) the average hydraulic gradient estimated at ERDF (0.0035) from water table conditions in December of 1991, 2) saturated hydraulic conductivity of the uppermost aquifer (30 m/day) estimated from pump tests results from wells near the ERDF, 3) an assumed saturated zone porosity of 0.30, 4) saturated zone density of 1.6 kg/L, and 5) a saturated zone mixing depth of 5 m.

The methodology described above and summarized in more detail in Appendix A of DOE/RL (1994b) was used to evaluate in more detail the various alternatives considered in the RI/FS including: 1) a no action alternative and 2) a series of alternatives focusing on specific design characteristics associated with the implementation of the ERDF. The latter set of alternatives considered the impacts of implementing various combinations of liners, low-infiltration soil barriers, RCRA-compliant barriers, and the Hanford Protective Barrier.

2.1.3 100-Area Remediation Activities

A number of modeling activities has been carried out recently in the 100 Areas to support focused feasibility studies and interim remedial actions. The activities briefly summarized here include:

- numerical simulation of strontium-90 transport from the 100-N Area liquid waste disposal facilities (LWDF's)
- evaluation of the N-Springs barrier and pump and treat system
- focused feasibility studies in the 100-H, 100-D, and 100-K areas
- design of the interim remedial action for the 100-H, 100-D, and 100-K areas.

2.1.3.1 100-N Area LWDF Simulation

Strontium-90 transport was simulated in the 100-N Area to estimate the effect of the LWDF on the future water quality of the unconfined aquifer at the shoreline of the Columbia River Connelly et al. (1990. This included estimating dose under a no-action alternative. Water levels were expected to change given the cessation of discharges to the LWDF.

VAM2DH was used to simulate a two-dimensional cross-section of the unsaturated and saturated zone. A similar study using the same code had been previously carried out for the 100-N Area (Lu, 1990). PORFLOW-3 was used to simulate flow and transport in a three-dimensional domain consisting of the unsaturated zone and the unconfined aquifer. Reasons given for using both models were compliance with in-house development and maintenance procedures and previous use at the Hanford Site. The PORFLOW-3 model used a Cartesian grid with variable grid spacing and a total number of 34,816 grid cells (32 by 34 by 34 grid cells).

The Columbia River was modeled as a constant head boundary that was allowed to vary over time according to the observed seasonal change in river elevation. The bottom of the model domain was a no-flow boundary, representing the upper mud unit of the Ringold formation. A small, constant flux was applied at the top boundary to represent long-term average recharge of 5 mm/yr. The remaining three sides of the domain were constant head boundaries, with the head values set to result in a gradient across the domain of 0.00095, the observed gradient in 1964 (the year discharges to the LWDF began). The discharge of water and strontium-90 from the LWDF was based on available data. Discharges were estimated for those years with no data.

Since the model explicitly simulated flow in the unsaturated zone, moisture retention characteristic parameters were required. These were estimated from ten soil samples obtained in the 100-N Area for this purpose. Parameters for each of the samples were estimated using a curve-fitting program. Parameters from the sample judged most representative were used in the numerical model (i.e., the unsaturated zone properties were

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homogeneous). The average saturated hydraulic conductivities were estimated from previous studies. Horizontal hydraulic conductivities were taken to be ten times the vertical values. Hydraulic conductivities were assumed to be homogeneous within the Hanford and the Ringold formations.

Effective porosity of the vadose zone was based on the moisture retention of the representative soil sample. Effective porosity in the aquifer was based on a previous study. Specific yield and dispersivities were based on literature values. The diffusion and distribution coefficients were based on previous studies of Hanford sediments.

Calibration using the flow model compared simulated and observed arrival times of a conservative solute and water table elevations in July 1969. The only parameter adjusted was the hydraulic conductivity. The arrival times and the water table elevations could not be simultaneously matched by varying the conductivity alone. The conductivity value chosen for use in the simulation was a value between that matching the arrival times and that matching the water table elevations.

Calibration of the solute transport model compared the simulated and observed concentration of strontium-90 at N Springs in 1974. The parameter adjusted was the distribution coefficient. A large value for this parameter was applied over a thin layer (0.68 m thick) beneath the strontium-90 source area to represent potential filtration of particulate strontium-90 by a sludge layer. The calibration simulation was carried out from 1964 to 1974, although there were no source term data for strontium-90 over the years 1964-1972. The limitation of this calibration analysis was recognized.

Results from the model were shown as plan and cross-sectional views of the water table elevation and the strontium-90 concentration. Travel paths were also shown. The simulation was carried out from 1964 (the start of discharge to the LWDF) to 2020. Strontium-90 concentrations at the river boundary and water flux into the river were used to calculate doses.

2.1.3.2   Evaluation of N-Springs Interim Remedial Action

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An additional model of the 100-N Area groundwater was developed to evaluate the ability of proposed interim remedial alternatives to limit the flux of strontium-90 into the Columbia River (DOE/RL, 1995e; see also DOE/RL ,1996a). The alternatives considered were a barrier wall, with and without a pump and treat system.

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Two codes were used in this modeling activity. Flowpath was used to model two-dimensional groundwater flow in plan view. PORFLOW was used to model 2-D flow and transport in cross-section. Both codes use the finite difference method. Both models looked at saturated flow only (i.e., flow and transport in the unsaturated zone were not considered). Both models used Cartesian grids with variable node spacing. The plan-view model based on Flowpath used 1334 nodes with cell size varying from 25 feet by 25 feet to 1000 feet by 500 feet. The cross-sectional model based on PORFLOW used 5100 nodes with cell size varying from 0.25 feet by 2 feet to 1 foot by 2 feet.

Steady-state flow conditions were assumed for both models. Although the daily and seasonal variation in the Columbia River stage was acknowledged, it was assumed that the presence of the barrier wall would lead to steady-state conditions in the region of concern. The head along the river boundary was set at the mean yearly river level from automated,

hourly measurements during 1993, taking into account the measured downstream river gradient. A no-flow condition was set along the vertical barrier wall. For the plan view model based on Flowpath, the top and bottom boundaries were no-flow (i.e., recharge and discharge to/from the confined aquifer were assumed to be nil). Sensitivity of the model results to a non-zero recharge was examined. The remainder of the boundaries were assumed to be constant head boundaries with individual nodal head values determined from an interpolated map of March 1994 water level measurements.

For the cross-sectional model based on PORFLOW, an assumption was made as to how high the steady-state water level would be in the presence of a vertical barrier wall. This assumption was based on the results of previous modeling. The water level value arrived at was applied to the up-gradient boundary for those cases in which a barrier was used. Top and bottom boundaries were no-flow as was the down-gradient boundary representing that portion of the aquifer under the river.

The transport portion of the cross-sectional model based on PORFLOW used constant concentration boundaries everywhere. Initial conditions for the transport set the relative concentration to one in the top 20 feet of the aquifer and to zero elsewhere. The transport boundary and initial conditions were based on previous reports that strontium-90 is limited to the top of the unconfined aquifer.

All parameters were assumed to be spatially homogeneous. Only the Ringold formation upper gravel unit and the upper mud unit were modeled. Horizontal hydraulic conductivity in the gravel unit was taken as the average value from six aquifer tests in the 100-N Area. Vertical hydraulic conductivity was taken as one-tenth the horizontal value. The conductivity in the mud unit was taken from the literature for a similar soil. For the mud unit, conductivity was isotropic in all but one case. Limited sensitivity analyses were conducted by adjusting the hydraulic conductivity used in the model.

Thickness of the unconfined aquifer was assumed to be constant and was based on existing data. For the cross-sectional model, the distribution coefficient for strontium-90 was determined by assuming a retardation factor of 100 based on previous studies. No explanation was given for the source of the bulk density and effective porosity values. For the cross-sectional model, the longitudinal dispersivity was set to 0.1 feet, approximately one-tenth the size of the grid cell. Transverse dispersivity was set at one-tenth the longitudinal value.

A number of remediation alternatives involving vertical barrier walls of different lengths and various number of pumping/injection wells were simulated with the plan view model. Strontium-90 concentrations at the river were estimated from calculated travel times and interpolated initial concentrations. The extraction wells were found to have a minimal effect on the flux of strontium-90 into the Columbia River. The effect on strontium-90 flux from varying the position of the bottom of the barrier water (from 1.2 m into the mud unit to 0.6 m above the mud unit) was examined with the cross-sectional model.

2.1.3.3 Bank Storage Modeling at 100-N Area

Previous modeling studies have been conducted at the 100-N Area to estimate the release of strontium-90 from groundwater to the Columbia River (Lu 1990; Connelly et al. 1990; DOE/RL 1995e, 1996a). All of these previous studies, except for Connelly et al. (1990), assumed a constant head boundary for the Columbia River based on the annual average of the river. Annual, seasonal, and daily changes to the Columbia River's stage are cyclical

and modeling the river on an annual average may not adequately describe the interaction between the Columbia River and the groundwater system at the 100-N Area.

A recent report by Connelly, Cole, and Williams (1997) documents modeling results from a recent application of a two-dimensional cross-sectional model of the Columbia River, unconfined aquifer, and vadose zone in the 100-N Area. The model, based on the Subsurface Transport Over Multiple Phases (STOMP) code (White and Oostrom. 1996. 1997; Nichols et al., 1997) was used to simulate the interaction between the rise and fall of the Columbia River and the unconfined aquifer and the capillary fringe directly above the water table in the 100-N Area.

The cross-sectional grid used consisted of 10,286 cells extending about 400 meters northwest of well 199-N-67. Grid cells varied in size from 0.5 by 0.5 m at the vadose zone seepage face to 3 by 0.5 meters away from the vadose zone seepage face. Of the 10,286 grid cells modeled, 3585 cells lie above the Columbia River bed or on the land surface.

The stratigraphy used in the modeling was based on geologic data from boreholes drilled in the 100-N Area. The two major hydrogeologic units considered included the Hanford Gravel and the Ringold Unit E, which is a variably cemented pebble to cobble gravel with a fine- to coarse-grained sand matrix. The vertical sequence modeled ranged from an elevation of 125 m to a depth of 107 meters, where the base of the model was assumed to be the top of the Ringold Mud unit.

Boundary conditions assumed in the model were as follows:

- The lower boundary on the top of the Ringold Mud Unit was assumed to be a no-flow boundary.

- The upper boundary was set to a natural recharge value of 2 cm/yr.

- The right boundary of the model was set at no flow in the vadose zone and to a time-dependent constant head boundary, which was varied on an hourly basis based real-time water level data recorded for well 199-N-67.

- The left boundary in the river was set as a no flow boundary

- Nodes on the river bed were set to a time-dependent constant head boundary based on real-time river stage measurements made at the 100-N Area river monitoring station.

Initial estimates of hydraulic conductivity and porosity were developed based on aquifer tests and soil analyses collected near the 1301-N and 1325-N facilities. Estimates of the unsaturated zone hydraulic properties were also made using available information on hydraulic conductivity, particle density, specific storage, porosity, and the assumed van Genuchten curve fitting parameters. The estimates of hydraulic conductivity and porosity were varied to calibrate the model to transient observed water level measurements in wells between the Columbia River and well 199-N-67.

A 125 hour transient simulation was used to develop initial conditions for a four-week period of simulation. During this period, the model was used to simulate the transient

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interaction of the Columbia River and the unconfined aquifer in one-hour time steps. Because of the large volume of data generated by the simulation, the modeling results were summarized in an innovative time-series animation of river stage and aquifer head fluctuations during the period of simulation. This animation was used to display changes in water travel times in the riverbank and water flux calculation to and from the Columbia River due to both bank storage and regional groundwater gradients.

Results of the modeling demonstrate that the variation in Columbia River stage has an impact on the near river unconfined aquifer system. A comparison of transient and steady state water particle tracking analysis showed that consideration of the cyclical transient conditions of the river can increase water velocities over velocities calculated for steady state conditions. Water mass calculations also demonstrated the importance of bank storage in calculating total water movement from the unconfined aquifer and the Columbia River at 100-N Area. Both of these factors need to be evaluated in the final design criteria for remediation technologies considered along the Columbia River at the 100-N Area.

2.1.3.4   Focused Feasibility Studies in the 100 Areas

Focused feasibility studies at the 100-HR-3 and 100-KR-4 groundwater operable units used groundwater flow and transport modeling to compare remediation alternatives for chromium contamination. These modeling activities are described in DOE/RL (1995a, b, and c). The modeling was not intended to be used for design purposes or for quantifying a measure of remediation effectiveness or efficiency. Separate models were developed for each of the areas within the two operable units. MODFLOW was selected for flow modeling based on its ability to simulate unconfined flow on a desktop computer. MT3D was used for transport because it is well documented and interfaces with MODFLOW.

Natural recharge was assumed to occur at a rate of 5 cm/yr. In the 100-H area, however, a recharge value of 7.3 cm/yr was used because this produced a better fit to water table data. it was assumed that there is no hydrologic communication between the unconfined aquifer and lower layers, that the contaminants are uniformly mixed throughout the aquifer depth, and that there is no source of chromium in the unsaturated zone. The Columbia River was modeled as a head-dependent flux boundary, with no change in depth of the river over the length of the model. Steady-state flow was modeled.

Elevations for the bottom of the model were derived from interpretation of contoured borehole data. Conductivities were determined in a calibration using the steady-state flow model and matching water table data from 11/16/93. For the 100-D Area model, a single layer for the aquifer was used. The hydraulic conductivity was uniform except for a limited area around a set of four wells. For the 100-H Area model, a second layer representing the Ringold formation was added to improve the calibrated fit. Different conductivities were used for the two layers of the model representing the Hanford and the Ringold formations. For the river, the bed thickness was assumed to be 1 m. The conductivity of the river bed was determined in the calibration. The River Package in MODFLOW was used to model the river.

A sensitivity analysis of the 100-D Area transport model was performed to gauge the sensitivity to porosity, dispersivity, and retardation. A calibration of the 100-H Area transport model was performed by adjusting model dispersivity, retardation and porosity. A table was provided listing the parameter values used in the calibration runs. Observed chromium concentration data from October and November 1992 was used to evaluate the calibration. The parameters resulting in the lowest mean error were used.

Various modifications to the basic model were made to simulate each of the remediation alternatives, including the modification of conductivities (to represent a barrier wall) and the location and pumping rates of injection/discharge wells. Simulation times varied from 14 to 21 years.

2.1.3.5 Interim Remedial Action Design in the 100 Areas

Additional models were developed of the 100-HR-3 and 100-KR-4 operable units to help determine the placement of new wells and the use of existing wells to support the pump and treat interim remedial action, and to estimate extraction/injection rates for design (ERC, 1996; DOE/RL, 1996b). The MicroFem code was used for this design study. This code is a two-dimensional finite element flow simulator with built-in pre- and post-processing and automatic (triangular) mesh generation. Stated reasons for selecting this code were the ability to get high-resolution grids around pumping and injection wells, use of the finite element method, capability to model transient and steady-state conditions (flow), and the generation of graphical output.

The Columbia River was assumed to be one of the boundaries for the 100-H, 100-D, and 100-K Area models. The river was modeled as a constant head boundary with the river stage known and constant in time. The flux through the river boundary was calculated as the product of a vertical resistance between the river and the aquifer and the difference in head between the river stage and the aquifer. The 100-H and 100-K Areas were felt to have no natural boundaries so the model boundaries were located far from the wells to minimize boundary effects. No-flow boundaries were adopted approximately perpendicular to the river and constant head boundaries were used parallel to the river. The constant head boundaries were place along the interpolated hydraulic head contours from water level measurements. For the 100-D Area model, constant head boundaries were used. These boundaries were based on knowledge of discharge across natural boundaries and on a water table map of June 1995. The bottom boundary was set to the Hanford and Ringold contact for the 100-H Area model and to the top of the upper mud unit of the Ringold formation at 100-D.

The model parameters required were transmissivity, porosity, and aquifer thickness. In all cases the aquifer porosity was assumed constant. For the 100-H Area model, a constant conductivity was assumed based on the average value of aquifer test results. A variable aquifer thickness was assigned based on interpolations of water level data and Hanford/Ringold contact data. Transmissivities were therefore spatially variable. Calibration was conducted using a steady-state flow model and comparing predicted and observed heads for 1/94 to 8/95. The resistance term between the river and the aquifer was varied.

For the 100-D Area model, aquifer thickness was assigned a uniform value because there was insufficient data to support a spatially variable thickness. Transmissivity was based on a weighted average of the Ringold and Hanford formation conductivities, which were average values from limited aquifer test data. Weighting was by the estimated thickness of the Hanford and Ringold formations. Calibration was conducted using a steady-state flow model and adjusting the constant head values at the boundaries and attempting to match water level data from 6/93 to 5/95.

For the 100-K Area model, thickness and transmissivity were assumed constant. Conductivity was based on limited aquifer test data. Calibration was similar to that used for the 100-D Area model.

Steady-state flow fields were calculated for the 100-D and 100-K Area models. Five-year transient simulations were carried out for the 100-H area. Streamlines and capture zones were calculated for a number of pump and treat scenarios (different well placements and injection/extraction rates). No simulations of contaminant transport were conducted, but concentrations in the 100-D Area were estimated based on the flow model results.

2.1.4 200-Area Remediation Activities

A capture zone analysis of the 200-UP-1 and 200-ZP-1 groundwater operable units has been carried out. These modeling analyses are described in WHC (1994);see also BHI 1996a, b). The stated objectives of this study were to evaluate alternative interim remedial actions, to assess refinements or expansions of interim actions, and to help choose a final remedy. Additional specific objectives were to assess impacts of changes in the water table elevation, to evaluate well configurations for the pump and treat, to design and evaluate monitoring networks, to evaluate hydraulic control and containment, and to predict contaminant transport pathways and travel times.

The VAM3DCG computer code was selected for the following stated reasons. It was being used for the site-wide modeling and thus the 200 Area results could be more easily integrated into the larger scale model. The finite element method used by VAM3DCG allows for non-rectangular elements and boundaries. VAM3DCG's use of transitional elements allows for a fine grid around wells and a coarse grid in areas with less steep gradients. The pseudo-soil function used in VAM3DCG provides an efficient means to approximate the water table condition and VAM3DCG has been approved for use on the Hanford Site.

The final three-dimensional grid used to model the 200 West Area had 19,383 elements, ranging in size from 600 m to 9.5 m in the horizontal direction. The vertical dimension was made up of six elements, equally divided over the depth of the unconfined aquifer at each node location in the horizontal plane.

The water table elevation as measured in June 1993 was used as the initial condition. The bottom boundary and the boundaries along Yakima Ridge and Gable Butte were no-flow boundaries. The remaining side boundaries were held at a constant head, with head values based on the June 1993 water table map. Artificial recharge from site operations was applied at appropriate locations, but the natural recharge was assumed to be zero. To represent the conditions in 1976, a large artificial recharge was applied to the center of the 200 West Area model and a steady-state simulation was performed. This steady-state solution was used as the initial condition for transient solutions in which the artificial recharge was gradually reduced. Recharge fluxes were based on previous studies.

Hydraulic conductivities were assigned based on a previous study (Connelly et al. 1992b) modified by more recent data. Where data did not exist, average values were used. Conductivity was uniform in the vertical direction except in a region where the aquifer becomes quite thin. Four of the elements in the vertical direction were made inactive in this region to avoid computational difficulties. Conductivities were isotropic in the horizontal

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plane. Vertical conductivity was assigned a value one-tenth the horizontal conductivity. A spatially uniform effective porosity value was used in the travel time calculations.

The transient simulation (with decreasing artificial recharge) used the steady-state simulation results as an initial condition for 1976. The simulation results were qualitatively compared to the June 1993 observed water table. Significant differences in the predicted and observed heads were noted, but no boundary conditions or parameter values were adjusted to provide a better fit.

Capture zones using one pumping and one injection well were calculated for various well locations and for times up to 150 days. In addition, the uncertainty in the spatial distribution of hydraulic conductivity was recognized and a single simulation was carried out in which the wells were located near a boundary between a high conductivity and a low conductivity zone. The capture zones were found to change drastically.

2.1.5 HRA/Land Use EIS

The Hanford Remedial Action and Comprehensive Land Use Environmental Impact Statement (DOE 1996a) was done to facilitate the change in Hanford's primary mission from production of nuclear materials for national defense to environmental restoration and long-term management of wastes. As part of this transition, the DOE must determine the optimum use of Hanford Site lands, facilities, and resources and how these lands and facilities should be remediated to allow for beneficial future uses. As a transition to the new mission, the Richland Environmental Restoration Project Plan was developed to provide information about the mission needs and objectives, technical planning, project schedule, and resource planning necessary for remediation of past-practice waste sites and surplus facilities.

The role of the EIS was to document, in the public forum, the process of determining the best combination of potential land uses, remediation benefits, and remediation costs. Through the EIS, the DOE responded to the need to

- evaluate the potential overall cumulative impacts from implementing the Richland Environmental Restoration Project Plan, including costs

- ensure that site-wide future land-use objectives are considered during the selection of remediation methods

- develop a comprehensive land use plan for the Hanford Site in accordance with DOE Order 430.1, Life-Cycle Asset Management

- identify the irreversible and irretrievable commitment of natural resources necessary to implement the Richland Environmental Restoration Project Plan.

As a part of this EIS, environmental consequence analyses were performed to evaluate the potential impacts of various land use alternatives. The future land-use alternatives considered are described as follows:

- Unrestricted Land Use. Residual contamination does not preclude any human uses; however, access or certain uses might be controlled for other reasons, (e.g.,

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physical hazards, cultural resource protection, habitat protection).

- Restricted Land Use. Residual contamination precludes some human uses; restrictions could apply to the use or disturbance of surface soils, subsurface soils, surface water, or groundwater.

- Exclusive Land Use. Potential health risks due to residual contamination would limit use and require strict controls on access. Use of the area would be limited to the management of radioactive and hazardous materials and similar and compatible uses. Control of the area would be maintained by the DOE. Exclusive-use areas would include buffer zones around active facilities.

To support the human health impacts of consequence analysis of these alternatives, an approach was developed that combined individual waste sites into groups and integrated the effects of potential releases to the environment. This was accomplished by grouping waste sites by medium (e.g., soils, groundwater), then aggregating the waste sites into 1-km² (0.4-mi²) cells in a grid overlaid on the Hanford Site. The potential contaminant release and transport through the environment from each 1-km² (0.4-mi²) cell was estimated using the Multimedia Environmental Pollutant Assessment System (MEPAS) computer model (Droppo1991), which was developed by the PNNL. Modeling results from multiple cells were combined to estimate the contaminant concentrations in the soil, groundwater, surface water, and air to which a human or ecological receptor might be exposed. Source-term data were compiled from the Waste Information Data System, Solid Waste Information Tracking System (SWITS), and Hanford Environmental Information System databases, and from field investigation reports and other sources, when applicable.

The risk to a given receptor was determined by estimating the quantity of contaminant transported from a source to that receptor. Risk calculations were simplified by separating the computational process into discrete modules. These modules include the source (waste) terms, contaminant transport mechanisms, exposure scenarios, and the variables used to calculate risk or hazard index from a given exposure. The MEPAS model was used to estimate risk.

To facilitate the transport analysis using the MEPAS code, flow paths were calculated based on December 1992 flow conditions (the most current represented by the model). It was assumed that those flow conditions remained constant for the duration of the particle tracking. Particle paths were started at elements that contained cells representing the waste and tracked until they reached a model boundary. Straight-line approximations to the flow paths were then used in MEPAS to describe the travel paths from waste sites.

To generate path-lines for input to MEPAS, the unconfined aquifer at the Hanford Site was simulated with the two-dimensional version of the Hanford Site groundwater model (Wurstner and Devary 1993). This model is based on the Coupled Fluid, Energy, and Solute Transport (CFEST) (Gupta et al. 1987) groundwater code integrated with an ARC/INFO database of site properties. The model is used to support work for the Hanford Groundwater Monitoring Project.

The commercially available geographic information system (GIS) ARC/INFO has been integrated with the CFEST groundwater modeling code (Cole et al. 1988; Gupta et al.1987). A series of ARC/INFO macro routines and FORTRAN utility programs have been developed to create an ARC/INFO-CFEST interface. For example, an ARC/INFO macro may be used to select elements that represent starting points for particle travel

analyses. A FORTRAN utility program would then generate a command file used to execute the CFEST travel path module. Another ARC/INFO macro has been written to create a triangular irregular network surface from CFEST output from which contour maps can be generated. Additional ARC/INFO macros for grid generation and parameter assignment are being used in support of the three-dimensional model development under the Hanford Groundwater Monitoring Project.

2.1.6 Hanford Groundwater Project

Groundwater modeling is being used to actively support key objectives of the Hanford Groundwater Project which include 1) to identify and quantify existing, emerging, or potential groundwater quality problems and 2) to assess the potential for contaminants to migrate from the Hanford Site through the groundwater pathway.

Two recent specific assessments related to the Hanford Groundwater Program that have made extensive use of groundwater modeling include

- Predicted impacts of future water-level declines on site-wide monitoring wells

- Development of a three-dimensional groundwater model and its application to evaluating the impacts of existing contaminant plume migration on Hanford Site drinking water systems and groundwater use

These two groundwater modeling efforts are briefly described below:

2.1.6.1 Predicted Impacts of Future Water-Level Declines on Site-Wide Monitoring Wells

In this study conducted in 1994 (Wurstner and Freshley 1994), a two-dimensional groundwater flow model based on the CFEST code was used to evaluate the impact of declining water levels on existing monitoring wells in the unconfined aquifer. The model was used to predict water-level declines in selected wells in the operating areas (100, 200, 300, and 400 Areas) and the 600 Area.

This early analysis using the two-dimensional site-wide model showed that the effect of declining discharges at the Hanford Site will be observed in the unconfined aquifer for several decades to come and that a large number of observation wells are expected to be impacted.

2.1.6.2 Evaluation of Impacts of Existing Contaminant Plume Migration on Hanford Site Drinking Water Systems and Groundwater Use

A three-dimensional numerical model of groundwater flow and transport based on the CFEST code, was developed for the Hanford Site to support the Hanford Groundwater Project managed by PNNL (Thorne and Chamness 1992, Thorne et al. 1993, Thorne et al. 1994 and Wurstner et al. 1995). The model was developed to increase the understanding and to better forecast the migration of several contaminant plumes being monitored by the project.

Recent modeling efforts have focused on continued refinement of an initial version of the three-dimensional model developed in 1995 (Wurstner et al., 1995) and its application to

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simulate future transport of selected contaminant plumes being monitored in the aquifer system. This version of the model was updated using a more current version of the CFEST code called CFEST-96.

In this conceptualization of the unconfined aquifer system, the lateral extent and relationships of the major hydrogeologic units of the Ringold and Hanford formations were defined. Contacts between these units were identified at as many wells as possible. These interpreted areal distributions and thicknesses were integrated into EarthVision, a three-dimensional visualization software package, which was then used to construct a database of the three-dimensional site conceptual model. The resulting conceptual model contains nine hydrogeologic units above the uppermost basalt. A brief summary of each of these units is provided in Table 1.

Prior to conducting simulations of contaminant transport with the three-dimensional model, a previous steady-state, two-dimensional model of the unconfined aquifer system (Jacobson and Freshley 1990) was re-calibrated to 1979 water-table conditions with a statistical inverse method implemented in the CFEST-INV computer code. The results of the re-calibration were used to refine the three-dimensional conceptual model and to calibrate it with a conceptualization that preserves the two-dimensional hydraulic properties and knowledge of the aquifer's three-dimensional properties for the same 1979 water-table conditions.

The transient behavior of the three-dimensional flow model was also calibrated by adjusting model storage properties (specific yield) until transient water-table predictions approximated observed water-table elevations between 1979 and 1996. Following the steady-state and transient calibrations, the three-dimensional model was applied to predict the future response of the water table to postulated changes in Hanford operations.

Over about a 300-year period following elimination of wastewater discharges to the ground at the site, the water table predicted by the model declined significantly and returned to near pre-Hanford water-table conditions that were estimated to exist in 1944. Over this period, model results showed that the water table will drop as much as 11 m in the 200-West Area and 7 to 8 m in the 200-East Area near B Pond. The areas that were predicted to be different from the estimated 1944 conditions included: 1) the area west of the 200 Area plateau, where higher predicted hydraulic heads reflect boundary conditions that consider the effect of increased irrigation from areas up-gradient of the modeled region; and 2) the area north of Richland, where the model considered the hydraulic effect of the North Richland well field.

Flow modeling results also suggested that as water levels drop in the vicinity of central areas in the model, the saturated thickness of the unconfined aquifer greatly decreases and may eventually dry out south of Gable Mountain along the southeast extension of the Gable Butte anticline. This phenomena would cause the unconfined aquifer to the north and south of this line to become hydrologically separated. As a result, flow paths from the 200-West area and the northern half of 200-East area which currently extend through the gap between Gable Butte and Gable Mountain may be effectively cut off in the future. In time, the overall water table, including groundwater mounds near the 200-East area will decline, and groundwater movement from the 200 Area plateau will shift to a more west-to-east pattern of flow toward points of discharge along the Columbia River between the Old Hanford town site and the Washington Public Power Supply System facility.

Table 1. Major Hydrogeologic Units Used for Three-Dimensional Model Developed by PNNL

Unit Number	Hydrogeologic Unit	Lithologic Description
1	Hanford formation/ Pre-Missoula Gravels	Fluvial gravels and coarse sands
2	Palouse Soil	Fine-grained sediments and eolian silts
3	Plio-Pleistocene Unit	Buried soil horizon containing caliche and basaltic gravels
4	Upper Ringold Mud	Fine-grained fluvial/lacustrine sediments
5	Middle Ringold	Semi-indurated coarse-grained fluvial sediments
6	Middle Ringold	Fine-grained sediments with some interbedded coarse-grained sediments
7	Middle Ringold	Coarse-grained sediments
8	Lower Ringold Mud	Lower blue or green clay or mud sequence
9	Basal Ringold	Fluvial sand and gravel

Area plateau. Each of the transport simulations was based on the predicted future transient-flow conditions, and a high-resolution, finite-element grid designed to resolve transport calculations in the areas of current and future contamination.

Projected future levels of tritium suggest that water supply wells in the 400-Area at the Fast Flux Test Facility (FFTF) and emergency water supply wells in the 200-East area will continue to be impacted by the tritium plume originating from the 200-East Area for the next 10 to 20 years. Tritium levels at well locations in the 400 Area and 200-East Area are expected to remain above the 20,000-pCi/l level until sometime between 2010 and 2020. After that time, tritium will continue to decline to below 500 pCi/l, at some time between the years 2070 and 2080. Model results suggest that tritium concentrations now found in the 300 Area in excess of 2,000 pCi/l will not reach the North Richland well field.

Transport analysis suggests that only water supplies in the 200-East Area could be impacted by elevated levels of iodine-129. Model-predicted levels of iodine-129 suggest that, within 20 to 30 years, iodine levels in excess of 1 pCi/l originating from the 200-East Area would be found about halfway to the Columbia River. The iodine-129 plumes originating from 200-West Area will be expected to migrate slowly toward 200-East Area but model results suggest that levels in excess of 1 pCi/l would not reach 200-East Area within 30 years.

Projected future levels of iodine-129, technetium-99, uranium, and strontium-90 show that none of the identified water supplies on the Hanford Site, including those in the 200-East

Area near B-Plant and AY/AZ tank farm, will be impacted by future transport of these contaminants.

2.1.7 Composite Analysis

In response to Recommendation 94-2 of the Defense Nuclear Facilities Safety Board (DNFSB), DOE has directed field sites to include in site performance assessments an analysis of the impact of other radioactive sources that could add to the dose from active or planned low-level waste (LLW) disposal facilities. In response to this, an initial composite analysis of the Hanford Site was initiated in FY 1996 and is currently being conducted as part of the Hanford Groundwater Project. This composite analysis is focusing on the 200 Area central plateau because of the variety of LLW facilities (e.g., 200 West and 200 East burial grounds, LLW from tank wastes, and the ERDF trench) impacted by the DNFSB recommendations. A draft document summarizing this initial assessment is scheduled to be completed by March 31, 1998

As a part of this effort, PNNL staff have been working closely with representatives of on-site programs to identify and screen all sources that could potentially interact with contaminants from Hanford LLW disposal facilities. Inventories of radionuclides that are expected to contribute to the predicted doses have been established for each of these sources. Forecasts of releases to the aquifer from major EM-Program Facilities (200 West LLW Burial Ground, 200 East Burial Grounds, ERDF Trench, and the low-activity wastes from the TWRS Program) have been obtained. Forecasts of release to the aquifer from pre-1988 wastes from EM-30 or EM-40 programs have been generated from reviews of inventory records. Forecasts of releases to the aquifer from residuals assumed in tank farms, commercial low-level radioactive waste facilities, liquid discharge facilities (i.e., ponds, cribs, and ditches), residuals assumed in separations facilities, and graphite cores from nine production reactors have also been estimated. A groundwater modeling strategy was developed to identify the scenarios and time frames to be modeled, the sources and radionuclides to be included, and the types of models to be used for calculating both the releases to the water table and long term flow and transport simulations in the unconfined aquifer.

The scope of the groundwater pathway analysis, which is based on the three-dimensional groundwater flow and transport model developed by PNNL under the Hanford Groundwater Project, is to assess dose impacts for the off-site transport of existing plumes and from future releases of contaminants in the 200 Areas. The transport analysis is examining the transport of these current and future contaminant plumes from present-day conditions to about the year 3000. The hydraulic basis for these future transport conditions was developed by using the three-dimensional model to simulate transient flow behavior of the unconfined aquifer in response to anticipated reductions in Hanford wastewater discharges in the near future. Model results show that the water table would reach near steady-state conditions within 100 years; final steady state would be reached by the year 2500.

Forecasts of concentrations of key radioactive contaminants simulated in the transport calculations provide the basis for final dose calculations using standard dose conversion methodologies and exposure scenarios and parameters identified by the HSRAM (DOE/RL 1995d). Dose impacts from the existing plumes and future releases of contaminants are being assessed in the area outside of the waste management exclusion areas and the surrounding buffer areas established by the Future Site Uses Working Group. Potential dose impacts to the public after site closure in 2050 for four potential exposure scenarios

derived from HSRAM (the agricultural, residential industrial, and recreational exposure scenarios) are being evaluated.

Because of the large uncertainties anticipated in current estimates of waste inventories. final end-states of many LLW disposal facilities, and the future releases of contaminants to the aquifer from the variety of potential sources in the 200 Area plateau, this initial composite analysis is being viewed as a first iteration that will require revisions and refinements as records of decisions and end-states of facilities are negotiated under the Tri-Party Agreement framework. The next iteration of the Composite Analysis is currently planned to be conducted starting FY 1999.

2.1.8 Columbia River Comprehensive Impact Assessment

To evaluate the impact to the Columbia River from Hanford-derived contaminants, the DOE, U.S. EPA, and the Washington State Department of Ecology (the Tri-Party Agreement agencies) initiated a study referred to as the Columbia River Comprehensive Impact Assessment (CRCIA). To address the concerns about the scope and direction of CRCIA as well as enhance regulator, tribal, stakeholder, and public involvement, a CRCIA management team, composed of representatives of the Confederated Tribes of the Umatilla Indian Nation, Nez Pierce Tribe, Yakama Indian Nation, the Hanford Advisory Board, Oregon State Department of Energy, the Tri-Party agencies, and Hanford contractors was formed in August 1995.

The CRCIA, under agreement among the CRCIA Team, was conducted using a phased approach. The first phase of the assessment included two components: 1) a screening assessment to evaluate the potential impact to the river resulting from current levels of Hanford-derived contaminants in order to support decisions on interim remedial measures being conducted in areas along the river and 2) a definition of the essential work remaining to provide an acceptable comprehensive river impact assessment. Both components of the CRCIA were completed and published in DOE/RL-1997. Of relevance to this effort is Part 2 of the CRCIA report, which described the requirements for a future Columbia River Comprehensive Impact Assessment. A brief synopsis of these requirements, as they apply to site-wide groundwater modeling, is provided below.

In Part 2 of the CRCIA report, several specific requirements were described. The assessment should include analysis of contaminant transport through the vadose zone and in groundwater and determinations of travel times to and concentrations of contaminants in the Columbia River. In addition, the uncertainty in these quantities must be assessed. Chemical and physical characteristics of the contaminants must be considered, including the dependence of these characteristics on soil type, groundwater chemistry, and the presence of other contaminants. Radioactive decay must also be included where applicable.

The CRCIA requirements express a concern for the spatial variability of groundwater influx to the Columbia River, whether through seeps, springs, or the river bottom, and the effect localized hot spots of contamination might have on river biota. In particular, groundwater influx locations must be identified and the expected contaminant flux at these locations estimated. This requires an understanding of the interaction between the river and groundwater and a spatial discretization that provides a realistic representation of critical points of exposure.

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A number of scenarios are required to be examined in the CRCIA analysis. These include modeling the groundwater recharge rate in such a way that the impact to the river from Hanford is maximized. Similarly, dilution of contaminants in the groundwater should be modeled to maximize the impact.

CRCIA requirements include an explicit, quantitative evaluation of the uncertainty in predicted impacts. This includes considering the uncertainty in the timing and magnitude of predicted peak concentrations. An explicit, documented definition and validation of model structure and the parameters used are required. When local-scale models are used, they must be consistently integrated with the larger-scale models, including the use of consistent boundary conditions and the maintenance of conservation laws across scales.

A comprehensive analysis is required for CRCIA. A suggestion is made that this can best be accomplished by performing successive, iterative analyses using progressively more refined models. In all cases, the analysis must include the dominant factors contributing to dose/risk, the analysis must have an acceptably low level of error, distortion, and bias, and the uncertainty in predictions must be quantified.

The CRCIA requirements also impose a number of software requirements on the design, implementation, and procurement of codes. These include code verification and validation, testing, and review.

2.2 Waste Management

Following is a review of project activities that have used groundwater modeling to support major objectives for the Waste Management Program. These summaries reflect information provided by RL technical project managers and contractor personnel from Fluor Daniel Northwest and Waste Management Federal Services Hanford. The modeling activities summarized include those associated with:

- performance assessments of solid waste burial grounds in the 200 East and West areas
- permitting of liquid effluent facilities including the state-approved Liquid Discharge Site associated with the ETF
- solid waste environmental impact statement

2.2.1 Performance Assessments of Solid Waste Burial Grounds in 200 Areas

Since September 26, 1988, performance assessment analyses have been required by DOE Order 5820.2A to demonstrate that DOE-operated waste disposal facilities containing DOE-generated low-level radioactive wastes can comply with performance objectives quantified in the order and summarized in Table 2. Two separate performance assessments (Wood et al, 1995 and 1996), that have included use of groundwater modeling have recently been completely for new solid low-level waste disposal facilities located in the 200 East and 200 West areas. The following is brief description of the scope and specific groundwater modeling activities carried out to support these analyses.

The performance assessment of the 200 East Area low-level burial grounds (LLBG) examined the long-term impacts of LLW and radioactive constituents of the low-level mixed wastes (LLMW) disposed in waste burial areas in two locations: 1) the active 218-

Table 2. Performance Objectives Used in the Performance Assessments of the 200 Solid LLW Burial Grounds

Exposure Pathway	Time Period (yr.)	Performance Objectives
All pathways	less than or equal to 10,000	25 mrem/yr.
Drinking Water	less than or equal to 10,000	4 mrem/yr.

E-10 burial ground and adjacent burial grounds in the northwest corner of the 200 East Area and 2) the active 218-E-12B burial ground and adjacent inactive burial grounds located in the northeast corner of 200 East Area. A separate analysis was included to examine the impacts of reactor compartment wastes disposed of in trench 94 of the 218-E-12B disposal facility. Low-level wastes disposed in active and inactive burial grounds before September 26, 1988, were not considered in this analysis.

The performance assessment of the 200 West Area low-level burial grounds (LLBG) examined the long-term impacts of LLW and radioactive constituents of the LLMW disposed in several active waste burial areas situated along the west boundary of 200 West Area. Burial grounds considered in the analysis included 218-W-3A, 218-W-3E, 218-W4C, and 218-W-5. Low-level wastes disposed in retired or inactive burial grounds before September 26, 1988, (218-W-2, 218-W-4A, 218-W-4B, and 218-W-11) were not considered in this analysis.

To address the performance objectives related to groundwater contamination, two groundwater exposure scenarios were considered. One scenario consisted of an all pathways exposure in which 1) radionuclides are leached from the disposal and are subsequently transported by infiltrating water through the vadose zone to the underlying unconfined aquifer, and 2) an individual drills a well that draws contaminated water for drinking, crop irrigation, and livestock production, and a dose is received by ingestion of contaminated water, crops, milk, and beef, direct exposure to gamma-producing radionuclides in soil, and inhalation of contaminated dust. The second exposure scenario involved a drinking water scenario where only ingestion of contaminated water from the unconfined aquifer was considered.

The conceptual model of the analyses by Wood et al. (1995 and 1996) focused on incorporating two general processes that fundamentally control projected concentrations of radionuclides released from the LLW disposal facilities in groundwater withdrawn from the unconfined aquifer from a downstream well: 1) the total radionuclide mass flux being leached from the disposal facility per unit time and 2) the dilution that occurs as the radionuclide activity mixes with the volume of groundwater determined by the regional flow characteristics to flow beneath the facilities. To represent these processes, Wood et al (1995 and 1996) assumed that the waste volume representative of the total wastes disposed in the LLW facilities could be approximated by a three dimensional rectangular box projected onto a two-dimensional plane oriented parallel to the general direction of groundwater flow.

The numerical representation of this conceptual model was established in a two-dimensional cross-sectional model based on the VAM3D-CG code developed by Huyakorn and Panday (1994) that extended from the disposal facility to the uppermost 5 meters of the unconfined aquifer. The position of the water table in the cross-section was estimated using the site-wide model developed for use in the performance assessment (see appendix E of Wood et al., 1996). The model was used to estimate steady-state post-Hanford site conditions underlying the various LLBG areas.

The radionuclide release modeling results for the representative two-dimensional cross-section were extrapolated to different waste volumes and waste inventories. The following points are key aspects of the extrapolation process:

- The cross-section oriented parallel to the direction of flow and the downstream receptor well are in the same plane. Given these constraints, all activity released from the facility reaches the water table and is captured by the volume of groundwater that passes beneath the facility and ultimately intersects the downstream well. Thus, the radionuclide concentration in the water withdrawn from the well is proportional to both the integrated flux exiting across the entire trench floor and the volume of groundwater into which the contaminants are released.

- The integrated flux is dominated by the selected release mechanism. Three conditions were considered in different cases in this analysis, including

    - advective releases where the radionuclide inventory was uniformly dispersed throughout the waste volume and was released by the infiltrating rainwater. In this case, the integrated flux is proportional to the radionuclide inventory and infiltration rate and is insensitive to the waste area of release.

    - solubility-controlled release in which chemical conditions impose a constant concentration in contaminated water leaving the facility. In this case, the flux is not proportional to the inventory; it is proportional to the assumed radionuclide concentration, the infiltration rate and the waste area over which the release is occurring.

    - diffusion-controlled release where radionuclide release rates are controlled by an assumed diffusion coefficient. In this case, the integrated flux is proportional to the inventory, the area-to-volume ratio of individual containers, and the diffusion coefficient.

- The volume of groundwater that mixes with the radionuclides released to the water table is proportional to the linear dimension of the waste volume footprint that is perpendicular to the direction of flow. Relatively little dispersion is allowed in the model and the area over which the groundwater and the contaminant plume intersect is essentially the same as that of the area underneath the waste volume. The orientation of the areal footprint of the waste volume relative to groundwater flow remains constant. Thus, as the linear dimension of the footprint perpendicular to flow decreases or increases, the volume of mixing groundwater increases or decreases.

2.2.2 Liquid Effluents Program Support

Under the Hanford Site State Waste Discharge Permit Program, the site discharges treated cooling and wastewater to the soil column at several locations in accordance with the Washington State Administrative Code (WAC) 173-216 and DOE Order 5400.5. Individual discharges permits include the following sites:

- ST-4500, 200 Area ETF managed by WMH-PHMC
- ST 4501 FFTF Secondary Cooling Tower Water managed by WHC-PHMC
- ST 4502 200 Area Treated Effluent Disposal Facility managed by WMH-PHMC
- ST 4503, 183-N Backwash Discharge Pond managed by BHI-ERC
- ST 4507 100-N Sewage Lagoon managed by Dyncor-PHMC
- ST 4508 Hydrotest, Maintenance, and Construction Discharges. This is a site-wide permit managed by both BHI-ERC and contractor personnel from the PHMC.

Of these facilities, the only facility that has used groundwater modeling is the 200 Area ETF. A summary of this recent modeling support is provided in the following section.

2.2.2.1 200 Area Effluent Treatment Facility

In 1997, groundwater modeling was performed to support ongoing permitting requirements for the ETF disposal site located just north of the 200 West Area (Barnett et al. 1997). The ETF, also known as the State-Approved Land Disposal Site (SALDS), receives treated effluent containing tritium which is allowed to infiltrate through the soil column to the water table. The facility operating permit promulgated by WAC 173-216 (Ecology 1986), requires groundwater monitoring for tritium, reporting of monitoring results, and periodic review of the monitoring network.

The ETF began operations in November 1995 and tritium was first detected in groundwater monitoring well around the facility in July 1996. The SALDS groundwater monitoring plan requires a reevaluation of the monitoring well network and a revision of the predictive groundwater used in the original permit one year after first detection of tritium in groundwater.

The three-dimensional site-wide groundwater model based on the CFEST-96 code (Gupta 1997), developed for use in the Hanford Groundwater Project by PNNL, was used to support this reevaluation of groundwater monitoring and facility performance. The site-wide model was used to simulate transient flow for the Hanford Site over the next 100 to 200 years. These predicted flow conditions were used to provide boundary conditions for a highly refined and detailed three-dimensional sub-model of the unconfined aquifer in the immediate vicinity of the SALDS.

A comparison of results from a number of numerical models applied to ETF in the past indicated that earlier predictions of facility performance which showed tritium migration from the SALDS reaching the Columbia River, were too simplified or overly conservative in their assumptions of source term release. The most recent modeling showed that, when reasonable projections of flow and tritium discharges at SALDS are used, concentrations of tritium above 500 pCi/l migrate no further than 1.5 km from the facility.

2.2.3 Solid Waste Environmental Impact Statement

DOE has announced its intent to prepare an environmental impact statement (EIS) for the Solid Waste Program at the Hanford Site. The Hanford Site Solid Waste Program manages several types of solid wastes at the Hanford Site, including low-level, mixed low-level, transuranic and mixed transuranic, and hazardous wastes, and contaminated equipment. Mixed wastes contain radioactive and hazardous components. Other solid waste types (i.e., municipal solid waste, high-level waste, remediation waste) and spent nuclear fuel are managed by other Hanford Site programs.

The Hanford Site Solid (Radioactive and Hazardous) Waste Program EIS will evaluate the potential environmental impacts associated with ongoing activities of the Hanford Site Solid Waste Program, the implementation of programmatic decisions resulting from the Final Waste Management Programmatic Environmental Impact Statement (WM PEIS, DOE/EIS-0200-F), and reasonably foreseeable treatment, storage, and disposal facilities/activities. The EIS will evaluate alternatives for management of the program's radioactive and hazardous wastes, including waste generated at the Hanford Site or received from offsite generators, during the same 20-year period evaluated by the WM PEIS. This EIS will comprehensively analyze impacts of the proposed action and reasonable alternatives, including potential cumulative impacts of other relevant past, present, and reasonably foreseeable activities.

2.3   Tank Waste Remediation System

The following is a review of project activities that have used groundwater modeling to support major objectives for the Tank Waste Remediation System Program. These summaries reflect information provided by RL technical project managers and contractor personnel from Jacobs Engineering Group, Inc. (JEGI) and Lockheed-Martin Hanford Company (LMHC). The modeling activities summarized include those associated with the following key TWRS projects:

- TWRS Environmental Impact Statement
- Hanford Tank Initiative
- Performance Assessment of the Hanford Low Activity Waste Disposal Facility

2.3.1   TWRS Environmental Impact Statement

This environmental impact statement addresses actions proposed by DOE to manage and dispose of radioactive, hazardous, and mixed waste within the Tank Waste Remediation System program at the site (DOE 1996b). The waste includes more that 177 million curies in about 212 million liters of waste stored or to be stored in underground tanks in the 200 Area plateau. This EIS also addresses DOE's plans to manage and dispose of 1930 capsules containing 68 million curies of cesium and strontium.

As part of this EIS, environmental consequence analyses were performed to evaluate the impacts of a number of tank waste management alternatives including continued management alternatives with no retrieval, minimal retrieval alternatives, partial retrieval

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alternatives, and extensive retrieval alternatives. The groundwater part of the consequence analysis evaluated contaminant transport through the saturated unconfined aquifer using the aquifer model based on the VAM2D code (Huyakorn et al. 1991) at each of the eight tank source areas and the LAW disposal facility.

A conceptual model was developed for the unconfined aquifer that included Hanford Site stratigraphy, the upper and lower aquifer boundaries, and a table of material units and corresponding flow and transport parameters. The conceptual model was used to guide the setup of the numerical model. A grid spacing of 250 m (820 ft) was established for the Hanford Site and overlain onto a site map containing physical features and the source area boundaries. Node numbers of model boundaries (e.g., basalt outcrop and sub-crop areas, river nodes, wastewater effluent discharge points, the eight tank source areas, and the LAW disposal facility) were determined to allow numerical representation of these features for the modeling effort.

The first phase of the modeling effort entailed establishing the steady-state flow field that was consistent with previous site-wide groundwater flow simulations (Wurstner and Devary 1993). This was accomplished by adopting, as closely as possible, the hydraulic parameters from the previous effort. This was necessary to generate the velocity field for subsequent contaminant transport simulations. The steady-state results with the VAM2D model clearly matched results previously reported. This effort made use of EarthVision and ARC/INFO software capabilities to translate parameter distributions used for the CFEST version of the site-wide model into formats suitable for use by VAM2D.

The steady-state flow field, which is one of the principal bases for the groundwater impacts assessment, was developed using December 1979 site-wide water level measurements because it was determined (Wurstner and Devary 1993) that this data set was most representative of steady-state conditions. Using this data set also meant that the mounding from U Pond and B Pond would be evident. The mounding was recognized as a present-day condition that may dissipate over the next several decades with changes in the site waste management practices. It is conservative from an overall groundwater concentration and risk perspective to determine groundwater impacts with the mounds in place because the vadose zone would be thinner in the 200 West and 200 East Areas and contaminant travel times would be faster to the groundwater, resulting in higher concentrations in groundwater and higher risk. The travel time in the unconfined aquifer to the Columbia River would not be materially affected by the groundwater mounds, compared to the vadose zone travel time. The approach based on the December 1979 water level data provides conservative, comparable results for each alternative, especially in light of the uncertainties of waste disposal practices and how they would affect the present groundwater mounds, future land use such as irrigation to the west of the site and on the site, uncertainty in the depth of contamination in the unconfined aquifer, and climate change.

Once the initial flow modeling was completed, input files were developed to perform transient transport modeling from each source area for each of the alternatives. The results of the vadose zone modeling were used to develop input records for the groundwater model. Consequently, each groundwater simulation calculated contaminant levels in the unconfined aquifer resulting from a single source area. These were later combined during post-processing to represent contaminant levels from all source areas.

The approach of performing separate contaminant transport simulations for each source area and each Kd group and later combining the results during post-processing allowed one model simulation to represent all contaminants with similar mobility from one source area.

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2.3.2 Hanford Tank Initiative - AX Tank Farm Retrieval Performance Evaluation Criteria Assessment

A screening level sensitivity analysis using the MEPAS code was carried out with the stated purposes of identifying and ranking transport parameters and evaluating the importance of transport processes in the vadose zone (JEGI, 1997). The screening analysis was intended to help focus development of more detailed two- and three-dimensional models and to help define the data needed to reduce uncertainties in the risk assessment process.

MEPAS was chosen because it is a screening code (i.e., it uses relatively simple models for flow and transport and thus is relatively undemanding computationally, and it can provide conservative results) and has a built-in sensitivity and uncertainty analysis capability. Other advantages cited include review by a number of government agencies and other groups, wide application, an integrated risk analysis using accepted procedures, a coupled database of chemical and radionuclide properties, and a user-friendly interface.

The structure of the MEPAS code required a steady-state flow analysis with one-dimensional flow in the unsaturated zone. Based on detailed geologic studies, a simplified, nine-layer vadose zone model was constructed for the AX tank farm. Soil parameters were based on data from a number of locations in and near the 200 East and West areas (Khaleel and Freeman, 1995). Distributions of parameters used in a probabilistic sensitivity analysis were obtained from the same data. Several scenarios were evaluated with the numerical model: the influence on transport of reduced sorption near the tank release, the influence of preferential transport via the annular space in boreholes or via clastic dikes, the effect of enhanced infiltration around the tanks, and the effect of unsaturated zone heterogeneity. The restrictions of the MEPAS code limited the ability to accurately model these transport mechanisms.

Detailed modeling at the AX Tank Farm is being carried out using the PORFLOW code for both the unsaturated and saturated zones (Personal communication, Phil Rogers, JEGI). The purpose of the detailed modeling is to evaluate alternative remediation and closure options at the AX tank farm. The saturated zone model is a two-dimensional site-wide model involving both groundwater flow and contaminant transport with risk as the endpoint. Parameters and boundary conditions of the numerical model are based on the parameters of the three-dimensional site-wide model of the Hanford Groundwater Project. A two-dimensional model was used in part to reduce the computational requirements of the analysis. PORFLOW was selected because it is on the list of approved codes for the Hanford Site and it was already being used by members of the project team. The two-dimensional model results will be compared to the three-dimensional Hanford Groundwater Project model results as a validation exercise. A preliminary draft report for DOE review is scheduled for completion in April 1998; a public draft is due in June 1998.

2.3.3 Hanford Low-Activity Waste Disposal Facility Performance Assessment

The Hanford low-activity waste disposal facility performance assessment provides an analysis of the long-term environmental and health impacts of the on-site disposal of Hanford low activity wastes (LAW). DOE/RL is currently proceeding with plans to permanently dispose of radioactive and mixed wastes that have accumulated over the last 50 years in single- and double-shell tanks in the 200 Areas of the site. Based on the Hanford Federal Facility Agreement and Consent Order (also known as the Tri-Party Agreement or

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TPA), waste currently stored in single- and double-shell tanks will be retrieved and pretreated to separate the low activity liquid fraction from the high-level and transuranic wastes. The LAW fraction will then be vitrified and disposed of on-site in a near-surface disposal facility located in 200 East Area.

DOE Order 5820.2A (DOE 1988), which is the primary regulation governing the management and disposal of radioactive wastes at DOE facilities, requires the preparation of an assessment of the long-term environmental and health impacts of the proposed disposal facility for DOE approval.

To date, an interim LAW performance assessment (ILAW PA) has been prepared to provide as early as possible an assessment of the effects of the disposals using available site-specific information. The initial draft of the ILAW PA was completed in FY 1996 and is currently under review. Final publication of the ILAW PA is planned for FY 1998. The data and information used in the calculations of the ILAW PA are summarized in Mann (1995). The data and information documented include the disposal site locations, geology, waste inventory, estimates of recharge, disposal package and facility design, release rates from glass waste forms, hydrologic parameters, geochemical parameters, and dosimetry. The data package also describes methods and technical approaches used to generate the values described.

Most of the data used in the ILAW PA is derived from information obtained in other on-site programs. The program intends to prepare a final LAW PA of the disposal facilities based on the more site-specific, waste-form specific, and facility-specific data that are planned to be generated over the next two to three years.

The proposed location for the TWRS LAW disposal complex includes two sites. The principal site, which is located in the south-central part of 200 East Area identified in Mann (1995) between the PUREX plant and the coal plant, will store the bulk of the LAW generated as wastes are retrieved from single-shell and double-shell tanks for vitrification by private vendors. Another site, which is located at the previously constructed grout disposal facility just east of the 200 East area, will be modified to receive initial quantities of vitrified wastes from private vendors while the principal waste disposal facility is being developed and constructed.

The ILAW PA analysis is currently being revised to provide the long-term environmental impact information needed by the Department to issue a Waste Disposal Authorization Statement which would allow the Richland Operations Office to proceed with needed interim steps of storage and eventual disposal including

- modification of four existing concrete disposal vaults at the grout site in order to provide access for the immobilized low-activity waste containers

- placement of the LAW containers and filler material in the modified vaults with the intent of future disposal in the grout facility

- construction of the first set of next-generation disposal facilities at the principle LAW waste site

- emplacement of LAW containers into these next generation disposal facilities.

The transport analysis of contaminants from the disposal facility considered the key physical and chemical processes causing release from the glass waste form and subsequent

vertical and lateral transport through the vadose zone to the underlying groundwater. Once in the groundwater, environmental and health impacts were evaluated 100 m down-gradient of the facility and at the Columbia River. Groundwater impacts down-gradient of the site considered the dilution of contaminated vadose zone water in groundwater and additional dilution created by a pumping well assumed for the family farm scenario.

The ILAW PA used the PORFLOW code to model both moisture flow and contaminant transport in the vadose zone and groundwater. Seven codes were investigated in detail, while an additional nine codes were considered based on earlier reviews. Although several codes had many of the required and desired features, the PORFLOW code was the only code considered to have all required and desired features. A major consideration was the use of PORFLOW in the Grout Facility Performance Assessment (Kincaid et al. 1995).

Flow and transport in the vadose zone from the LAW disposal facility was represented numerically in a two-dimensional axial-symmetric cross-section extending from the disposal facility through the Hanford and Ringold formations in the vadose zone to the water table. Releases calculated at the water table were then input to a two dimensional version of the site-wide groundwater model based on the PORFLOW code. Development of parameter estimates for the site-wide model was based on the hydraulic properties used in the site-wide model developed by BHI based on the VAM3DCG code.

3.0 Summary of Needs and Requirements

This section of the report provides a summary of recommended needs and requirements identified for consolidation of site-wide groundwater modeling in this initial assessment. These recommendations were developed based on a review of the objectives and attributes of implementations of groundwater models for ongoing and planned projects within the Environmental Restoration, Waste Management, and Tank Waste Remediation System programs briefly described in Section 2. Comparative summaries of the status, objectives, drivers and modeling attributes of all the modeling activities described are provided in a series of tables (Tables A.1, A.2, A.3, and A.4) in the Appendix of this report. The development of needs and requirements also made use of concepts and principles developed in previous work on code selection criteria developed by Westinghouse Hanford Company (WHC) (DOE/RL, 1991) in support of the ER program and FDNW in support of the TWRS Program.

The recommended needs and requirements for the consensus site-wide groundwater model are divided in four subsections that discuss the following areas:

- Modeling Objectives
- Conceptual Model and Database Needs and Requirements
- Computer Code Requirements
- Other Needs and Requirements related to long-term maintenance and care of the consolidated site wide model and processes needed to foster consistency in modeling applications.

3.1 Modeling Objectives

In defining the needs and requirements of a consolidated site-wide groundwater model, the objectives of the modeling study must be considered. At the Hanford Site, groundwater modeling applications have been carried out to satisfy a number of objectives. These objectives, which also apply to future modeling applications, include the following:

- preliminary screening of sites for locating waste disposal facilities
- site performance assessments of proposed waste disposal facilities
- assessment of environmental impacts involving the prediction of contaminant transport and dose modeling for
    - site-wide assessments (Composite Analysis, Columbia River Comprehensive Impact Assessment)
    - local-scale assessments.
- design and evaluation of groundwater remediation strategies including natural attenuation, hydraulic control/containment and, contaminant removal/cleanup
- design and evaluation of site monitoring networks to predict:
    - fate and transport of existing and emerging contaminant plumes

- transient hydraulic behavior of the water table and unconfined aquifer system in response to changing waste management practices, environmental restoration alternatives or waste facilities end states

- performance of groundwater remediation alternatives, and

• risk assessments

Although these modeling objectives result in different, and sometimes opposing, requirements for the models, there are a substantial number of shared needs and requirements.

3.2 Conceptual Model and Database Needs and Requirements

The primary commonality among groundwater modeling efforts at the Hanford Site is the collection of data on which the conceptual and numerical models are based. These data consist of geologic and hydrologic measurements that have been collected on regional and local scales to support various activities at the Hanford Site. The Hanford Environmental Information System (HEIS), the Hanford Geographic Information System (HGIS), and the Well Documentation System (WELLDOCS) are the primary repositories of data gathered during groundwater and environmental monitoring at the Hanford Site. These data cannot often be used directly in a numerical groundwater flow and transport model, however, without a significant amount of analysis and interpretation. For example, well logs undergo a geologic interpretation to identify the stratigraphy of the aquifer. This interpretation is then used to produce such information as a map of the top of the basalt, or a map of the location of the contact between the Hanford and Ringold formations. Such maps can be used to develop parameter distributions (e.g., develop the three-dimensional geometry of significant hydrogeologic units) for a numerical model, but are based solely on the data and do not depend on any particular numerical model or computer code that might be used.

The modeling activities currently under PNNL's Groundwater Monitoring Project use a system designed to separate the specific numerical model parameter estimates , particularly the grid and assignment of hydraulic properties, from the interpreted geologic and hydrologic characterization data (Wurstner et al. 1995). A database has been developed and maintained in an ARC/INFO GIS that contains the information necessary to develop parameter distributions for use in a site-wide model, including geologic data (e.g., geometry of the main hydrogeologic units), hydraulic property estimates, boundary conditions, initial conditions, locations and volumes of sources and sinks, and natural recharge estimates.

The advantage of such a site-wide modeling database is that the model information is stored in a form independent of the computer code used or the assumptions made for a particular modeling study. By storing this information as high resolution, regularly gridded data within the ARC/INFO GIS system, it is possible to use the model information at different scales (e.g., in sub-models) or with different groundwater computer codes. This allows for use of the numerical representation and computer code that is most appropriate for simulating the problem being considered. Currently, links have been created between ARC/INFO and the CFEST code, but creating links to other groundwater flow and transport codes, as was demonstrated in the VAM2D implementation for the TWRS-EIS, is possible so that a suite of codes would be available for use at the Hanford Site.

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An additional advantage of the site-wide model parameter database is that it can be based on a current consensus interpretation of the characterization data and can be updated as new data become available. The baseline geohydrologic condition is well established for the unconfined aquifer (Hartman and Dresel 1996, Wurstner et al 1995; Law et al. 1996, and Connelly et al. 1992a and b,). However, because data continue to be gathered and because newly gathered data do not always fit the existing conceptual model, a continuous effort is required to continually evaluate the data and refine the geologic and hydrogeologic conceptual models. As active and planned disposals and remediation sites are characterized, our knowledge grows regarding the vadose zone beneath these sites. Sediment or contaminant profiles (or both) beneath several sites have been studied in recent years and greatly expanded our knowledge of the vadose zone. Studies conducted for the proposed grout disposal facility and the 200-BP-1 crib site, and the ongoing study of recharge and soil hydraulic properties at the proposed disposal site for low-activity waste from tank wastes are examples. Because an up-to-date site-wide modeling database would be the basis for all modeling studies at the Hanford Site, this approach will minimize inconsistencies in model applications.

A site-wide model parameter database should be based primarily on data contained in available site-wide database systems. In addition to HEIS, they would include a number of user-tailored database systems that are separate from, but coordinated with, HEIS. These systems include the HGIS, the Geosciences Data Analysis Toolkit (GeoDAT), and WELLDOCS databases. The information contained in these databases can be processed using available GIS software such as ARC/INFO and EarthVision to develop parameter distributions for model applications. Numerous other smaller database systems also exist. Portions of these databases may be applicable to a site-wide modeling database. Redundancies should be minimized and databases combined as appropriate.

In a sense, the site-wide model parameter database should represent the most complete and complex conceptual model in use at the Hanford Site. Because of the multiple modeling objectives in use at the Hanford Site (see list above), however, it is likely that more than one conceptual model may be appropriate. Currently, the conceptual model of the unconfined aquifer at Hanford developed by the surveillance program at PNNL includes ten layers representing the Hanford formation, Ringold formation and underlying basalt (Wurstner et al 1995, Thorne et al 1993, Thorne and Chamness 1992). The conceptual model developed by BHI and WHC in support of RCRA and CERCLA sites at Hanford includes three layers representing the Hanford formation and Ringold formation, and includes an impermeable lower boundary, the basalt. The conceptual model used in support of the Hanford Tank Initiative represents the unconfined aquifer as a single layer. The assumptions embodied in these conceptual models and the methods used to develop parameter distributions for the associated numerical models are different. Documentation should be maintained that demonstrates the consistency of all groundwater conceptual models in use at the Hanford Site.

To summarize, the major needs and requirements for a consolidated site-wide groundwater modeling program with respect to the conceptual model are as follows:

- A common site-wide database based on a GIS, containing all the information necessary to develop parameter distributions for use in a model should be used in all modeling applications.

- This model parameter database should be based on a consensus interpretation of the available data.

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- The database and data interpretations should be updated as new data, on both the local and regional scale, become available.

- Any conceptual models that make additional simplifications to the site-wide modeling database should include adequate documentation to demonstrate consistency. Such documentation may include a list of assumptions made, their justification, and comparisons with simulation results based on the most complete and complex conceptual model.

3.3 Computer Code Needs and Requirements

The particular objectives of the modeling study and the associated conceptual model needed to achieve these objectives will determine the needs and requirements of the computer code(s) used. Since it is possible, however, that a single code will be adopted in the future for all site-wide groundwater modeling, the needs and requirements in this section were developed for the most complex conceptual model and difficult modeling objectives likely to be needed at the Hanford Site for site-wide modeling.

3.3.1 Technical Requirements

3.3.1.1. Fluid Flow

In general, the selected code should be capable of simulating two- and three-dimensional saturated confined and unconfined flow of constant-density groundwater in an isothermal setting for either steady state or transient flow-field conditions. However, for certain modeling applications such as the simulation of remediation options for the carbon tetrachloride plume in the 200 areas or the evaluation of innovative in-situ treatment technologies such as in-situ REDOX treatment methodologies, capabilities to simulate the effects of variable density would be desirable.

3.3.1.2 Hydrologic Properties

The code should be capable of accommodating the three-dimensional geometry of the important hydrogeologic units and the three-dimensional spatial variation of hydraulic parameters (hydraulic conductivity, transmissivity, specific storage, storage coefficient, etc.) in important geohydrologic features. The code should allow anisotropic hydraulic conductivity values.

3.3.1.3. Unconfined and Confined Aquifer Conditions

The selected code should be capable of simulating flow and contaminant transport in unconfined and confined aquifer systems.

3.3.1.4 Spatial Scale of Analysis

The selected code should be capable of simulating flow conditions at the scale of the entire Hanford Site and have robust sub-modeling capability to facilitate the systematic transfer of attributes of the site-wide flow and contaminant transport model to local-scale models as appropriate.

3.3.1.5 Temporal Scale of Analysis

The selected code should have the capability to effectively simulate flow on a variety of time-scales ranging from a few years to 10,000 years at both the scale of the entire Hanford Site and at the local scale.

3.3.1.6 Contaminant Transport

The selected code should be capable of simulating contaminant fluxes in two- and three-dimensions as a function of the various driving hydrologic processes and mass transport phenomena, including advection, hydrodynamic dispersion, molecular diffusion, and adsorption.

3.3.1.7 Geochemical Model

The code should be able to represent geochemical retardation using a linear equilibrium adsorption model where the distribution coefficient depends only on the contaminant and on spatial position.

3.3.1.8 Radioactive Decay

The selected code should be able to treat the effects of radioactive decay. Another desirable but not required feature would include capabilities to analyze the effects of complex decay chains (for example, the decay of uranium).

3.3.1.9 Coupling of Flow and Contaminant Transport

The selected code should contain sufficient capabilities for site analysts to efficiently simulate flow conditions only, contaminant transport based on previously simulated flow conditions, or combined flow and contaminant transport.

3.3.1.10 Particle Tracking Capabilities

The selected code should contain sufficient capabilities for site analysts to efficiently perform streamline (for steady-state conditions) and pathline (for transient conditions) analyses in two- and three-dimensions.

3.3.1.11 Boundary Conditions

The selected code should be capable of incorporating time-dependent and spatially varying boundary conditions. The code should be capable of simulating homogeneous and non-homogeneous Dirichlet (constant head/concentration) and Neuman (constant flux) boundary conditions. The selected code should also have a prescribed approach for incorporation of time- and space-dependent sources and sinks of water and contaminant.

3.3.2 Administrative Requirements

3.3.2.1 User Interface Issues

Pre- and Post-processing Software. The code should interface with some form of pre- and post-processing modules that allow the user to readily set up problems and to understand

results. Graphical interfaces are preferred to text interfaces. Such pre- and post-processing modules could be an integral part of the code. In particular, the capability to graphically display the numerical grid discretization along with zone identifiers, contaminant and water fluxes across selected boundaries and/or regions in the modeling domain, and contours, spatial cross sections, and time histories of contaminant concentrations is highly desired. The pre- and post-processing systems can be commercial or public domain products not developed by those responsible for the computer code.

Coupling with Geographic Information System. The code should have the capability to receive and produce inputs or outputs to facilitate its use with the available site GIS's. Linkage to site GIS's and the site-wide model parameter database(s) would allow for the efficient specification of hydraulic properties, boundary and initial conditions, and sources and sinks.

3.3.2.2 Model Reliability Issues

The selected code should have evidence of reliability including adequate documentation, verification against a set of test problems relevant to Hanford groundwater conditions, and a body of model applications that can demonstrate its technical, regulatory, and public acceptance. Following is a brief description of each of these areas.

Code Documentation. Documentation should be readily available and cover the theory, governing equations, assumptions, solution methods, and user's guide. The code documentation provides a reference for those who want to evaluate the numerical model as well as a reference for the actual development and application of a numerical model for a particular problem. The user's guide should include a description of the input required, including the implementation of all execution options and any formatting requirements. A description of the output options should also be included in the user's guide. If graphical user interfaces to assist in the development of input files and the display of output files are distributed with the code, these should be documented in the user's guide. Even though graphical user interfaces may be available, the flat files used to contain the input and output should be described, including formatting and the location of parameters.

Code Verification. Evidence of verification should include comparison of the code results for a variety of known or accepted solutions. The verification provides evidence that the solution methods used in the code are correctly implemented and should also demonstrate the effect of the assumptions and potential errors arising from limitations of the code.

Body of Model Applications. The selected code should be well regarded among the user and regulatory community. In particular, the code should be acceptable to the U.S. Environmental Protection Agency and the Washington State Department of Ecology for environmental assessments at the Hanford Site. The code should have been used in simulations of the Hanford Site unconfined aquifer with the results published in externally reviewed documents.

3.3.2.3. Availability and Cost

The executable code should be available to the public at a reasonable cost for the purposes of repeating calculations and confirming results.

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3.3.2.4 Accessibility and Cross Contractor Use

The code must be available for use by all contractors performing Hanford Site groundwater modeling.

3.3.2.5 Code Availability and Version Control

The version of the code should be a recent version, preferably the last one that has been fully tested. For codes that are well established, the use of a well-tested version may outweigh the use of a newer, but less tested version. The software should be maintained under a quality control program that documents modifications.

3.3.2.6 Simulation Efficiency

The selected code should have a variety of computational algorithms and solvers to facilitate the efficient simulation of a wide variety of flow and contaminant transport problems.

3.3.2.7 Portability

The selected code should be capable of being run on a variety of computational workstations and platforms including UNIX-based workstations.

3.3.2.8 Proprietary Codes

Proprietary codes will be considered if they provide an advantage over public domain codes and only if the author(s)/custodian(s) allow inspection and verification of the source code by DOE and its agents. These inspections and/or verification reviews may be required to assist DOE and its contractors to rectify problems encountered in application of the code or in working with the code author(s) to develop technical approaches for required code enhancements.

3.3.2.8 Technical Support

The selected code should be sufficiently well documented and well-supported by the code developer to allow rectification of technical difficulties that arise in its application to Hanford specific applications.

3.3 Other Needs and Requirements

One of the major needs identified in the initial assessment is for a process to foster greater consistency in applications of groundwater models by various on-site programs. Because of the current organizational framework of the Hanford Site around major programs and the partitioning of technical work and responsibility among the various site contractors, groundwater modeling being conducted to support individual projects or programs has yielded results that were inconsistent with those generated by modeling groups in other programs. The identified inconsistencies in results, in most cases, have found their root causes from differences in

- the modeling objectives
- the definition of the conceptual model arising from differences in the sources and interpretations of data and the assumptions made

- the definition of the model boundary conditions

- the development of parameter distributions used in the numerical model, including the method of calibration

- the computer code(s) used (e.g., two versus three dimensions)

- the numerical model discretization, typically chosen to balance accuracy and the amount of time/money available

- interpretation of numerical model results, including estimates of uncertainty and accuracy of results, (e.g., two results may be different, but are not distinguishable from each other given the precision of the results).

Minimizing inconsistencies in model results may best be achieved by standardizing a conceptual model around a site-wide modeling database as discussed above. In addition, some effort should be made toward ensuring consistent development of parameter estimates for of models. Equally important should be a requirement to estimate the uncertainty in model results and the development of standard procedures to do so. The site may consider development of a process for review of key groundwater modeling assessments similar to what is currently being done for major environmental dose calculations. Currently, the site has in place the Hanford Environmental Dose Overview Panel (HEDOP). The panel is composed of representatives from the various contractors conducting environmental dose assessments on the site. Their current charter is to provide site wide review service, consistency checks, and guidance for studies and assessments that make use of environmental dose calculations. A similar panel could provide this type of review for groundwater modeling activities.

Another need identified in this assessment is the need for the site to make a commitment to support the long-term maintenance and care of the site-wide model. This commitment would include a development and implementation of a plan for

- maintaining the selected computer code(s) and associated conceptual model and numerical model parameter databases in appropriate configuration control

- maintaining a detailed administrative record of changes to
  - conceptual model interpretations and related model parameter databases
  - development of new parameter estimates for the numerical model as re-calibration is done in response to new information on geology, hydraulic testing, or water level measurements
  - selected codes and related software as new capabilities are incorporated or updated versions of the codes are acquired

- testing and evaluation of the numerical model in response to code modifications or updates to the numerical model parameter estimates

- identification and implementation of model capabilities based on improved:
  - transport theory (e.g., chemical reactive transport)
  - computational and numerical methods
  - computational equipment

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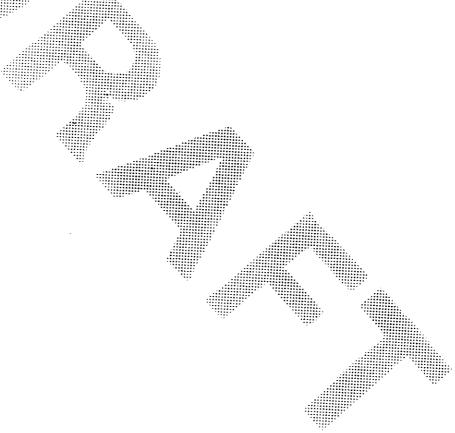
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APPENDIX:

ATTRIBUTES OF MODELING ASSESSMENTS PERFORMED IN
ENVIRONMENTAL RESTORATION, WASTE MANAGEMENT, AND
TANK WASTE REMEDIATION SYSTEM PROGRAMS

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APPENDIX

ATTRIBUTES OF MODELING ASSESSMENTS PERFORMED IN ENVIRONMENTAL RESTORATION, WASTE MANAGEMENT, AND TANK WASTE REMEDIATION SYSTEM PROGRAMS

This appendix contains comparative summaries of the status, objectives, drivers and modeling attributes of all the modeling activities described in Section 2 of this report. The information is summarized in a series of tables (Table A.1, A.2, A.3, and A.4) and is based on a review of the objectives and attributes of implementations of groundwater models for ongoing and planned projects provided to project staff by DOE/RL and contractor representatives of the Environmental Restoration, Waste Management, and Tank Waste Remediation System Programs. These summaries were also developed in part from information gathered during consultations with U. S. Environmental Protection Agency, the Washington State Department of Ecology, the Nez Pierce Indian Nation, the Yakama Indian Nation, and the ER subcommittee of the Hanford Advisory Board.

Table A.1. Model Attributes of Key Projects in the Environmental Restoration Program

Model Attributes	100-N Area Modeling		Interim Remedial Action Design Analyses					Focused Feasibility Studies	
	LWDF's	Bank Storage	N Springs	100-H Area	100-D Area	200 UP-1	200 ZP-1	100-H Area	100-D Area
Current Status									
Work Completed									
No future work needed									
Future Revisions Needed	x	x	x	x	x	x	x	x	x
Work Initiated									
Work Planned and In Baseline									
Work Planned and not in Baseline									
Drivers									
CERCLA	x	x	x	x	x	x	x	x	x
RCRA Compliance									
NEPA									
DOE Orders									
Facility Permitting									
Emergency Response									
Public Interest									
Purpose or Objective of Analysis									
Disposal Site Screening Analysis									
Site Performance Assessment									
Design and Evaluation of Remediation Strategy	x	x	x	x	x	x	x	x	x
Assessment of Environmental Impacts									
Evaluation of Monitoring Network and Design									
Risk Assessment									

Table A.1. Model Attributes of Key Projects in the Environmental Restoration Program

Model Attributes	100-N Area Modeling		Interim Remedial Action Design Analyses					Focused Feasibility Studies	
	LWDF's	Bank Storage	N Springs	100-H Area	100-D Area	200 UP-1	200 ZP-1	100-H Area	100-D Area
Scope of Analysis									
Dimensionality	3-D	2-D	2-D	2-D	2-D	3-D	3-D	3-D	3-D
Model Orientation		Cross-section	Areal/ X-sect	Areal	Areal				
Flow Analysis									
Vadose Zone Flow	Transient	Transient							
Groundwater Flow	Transient	Transient	Steady-state	Transient	Steady-state	Transient	Transient	Steady-state	Steady-state
Transport Analysis									
Vadose Zone Transport	Transient								
Groundwater Transport	Transient		Transient					Transient	Transient
Geochemical Capabilities Used/Required									
Sorption	x		x					x	x
Radioactive Decay w/o chain decay	x		x						
Radioactive Decay with Chain Decay									
Scale of Analysis									
Spatial Scale	Local	Local	Local	Local	Local	Local	Local	Local	Local
Time Scale	<50 yrs	<50 yrs	<200 yrs	<50 yrs	<50 yrs	<50 yrs	<50 yrs	<50 yrs	<50 yrs
Codes Used									
VAM3DCG						GW	GW		
PORFLOW	VZ/GW		GW						
STOMP		VZ/GW							
MEPAS									
CFEST-SC or CFEST-96									
MICROFEM				GW	GW				
MODFLOW								GW	GW
MT3D								GW	GW
Spreadsheet Analysis									
Flowpath			GW						

n/a not applicable; VZ vadose zone; GW groundwater   A.4

Table A.1. Model Attributes of Key Projects in the Environmental Restoration Program

Model Attributes	100-N Area Modeling		N Springs	Interim Remedial Action Design Analyses				Focused Feasibility Studies	
	LWDF's	Bank Storage	N Springs	100-H Area	100-D Area	200 UP-1	200 ZP-1	100-H Area	100-D Area
Boundary Conditions									
Basalt Outcrops	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cold Creek Valley	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Dry Creek Valley	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Yakima River	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Columbia River						n/a	n/a		
Constant Head	Transient	Transient	Transient	Steady-state	Steady-state			Steady-state	Steady-state
Constant Flux									
Local-scale Boundaries									
Constant Head	Steady-state	Steady-state	SS & Trans	Steady-state	Steady-state	Steady-state	Steady-state	Steady-state	Steady-state
Constant Flux									
Natural Recharge	x	x						x	x
Base of Model									
5 m below Water Table									
Hanford/Ringold Contact				x					
Top of Lower Ringold Mud Unit	x	x	x		x	x	x	x	x
Top of Columbia River Basalts						x			x

n/a not applicable; VZ vadose zone; GW groundwater

Table A.1. Model Attributes of Key Projects in the Environmental Restoration Program

Model Attributes	100-N Area Modeling		N Springs	Interim Remedial Action Design Analyses				Focused Feasibility Studies	
	LWDF's	Bank Storage		100-H Area	100-D Area	200 UP-1	200 ZP-1	100-H Area	100-D Area
Hydrostratigraphic Units	2	2	2	1	1	2	2	1	2
Hanford Formation	x	x	x	x		x	x	x	x
Ringold Formation (as single unit)	x	x	x			x	x		x
Combined Hanford / Ringold Formation					x				
Palouse Soil									
Plio-Pliestocene Unit									
Upper Ringold (Unit 4)									
Middle Ringold (Unit 5)									
Middle Ringold (Unit 6)									
Middle Ringold (Unit 7)									
Lower Ringold (Unit 8)									
Basal Ringold (Unit 9)									
Columbia River Basalt									
Contaminants Considered		n/a							
Radionuclides	Sr^{90}		Sr^{90}						
Chemicals								Chromium	Chromium

n/a not applicable; VZ vadose zone; GW groundwater

Table A.2. Model Attributes of Key Projects in the Environmental Restoration Program

Model Attributes	Hanford Site-Wide Remediation Strategy	Environmental Restoration Disposal Facility	Hanford Remedial Action/Land Use EIS	200 Area Soil Remediation
Current Status				
Work Completed				
No future work needed				
Future Revisions Needed	x	x	x	
Work Initiated				x
Work Planned and In Baseline				
Work Planned and not in Baseline				
Drivers				
CERCLA	x	x		x
RCRA Compliance				
NEPA			x	
DOE Orders				
Facility Permitting				
Emergency Response				
Public Interest				
Purpose or Objective of Analysis				
Disposal Site Screening Analysis				
Site Performance Assessment		x		
Design and Evaluation of Remediation Strategy	x	x		x
Assessment of Environmental Impacts		x	x	x
Evaluation of Monitoring Network and Design				
Risk Assessment		x		x

n/a not applicable; VZ vadose zone; GW groundwater

A.7

Table A.2. Model Attributes of Key Projects in the Environmental Restoration Program

Model Attributes	Hanford Site-Wide Remediation Strategy	Environmental Restoration Disposal Facility	Hanford Remedial Action/Land Use EIS	200 Area Soil Remediation
Scope of Analysis				
Dimensionality	3-D	1-D	2-D	?
Model Orientation		Cross-section	Areal	?
Flow Analysis				
Vadose Zone Flow		Steady-state	Steady-state	x
Groundwater Flow	Transient	Steady-state	Steady-state	x
Transport Analysis				x
Vadose Zone Transport		Steady-state	Steady-state	
Groundwater Transport	Transient	Steady-state	Steady-state	x
Geochemical Capabilities Used/Required				x
Sorption	x	x	x	
Radioactive Decay w/o chain decay	x	x	x	
Radioactive Decay with Chain Decay				
Scale of Analysis				
Spatial Scale	Site-wide	Local	Site-wide	Local/ Site-wide
Time Scale	<200 yrs	<10,000 yrs	<10,000 yrs	
Codes Used				
VAM3DCG	GW			?
PORFLOW				
STOMP				
MEPAS			VZ/GW	
CFEST-SC or CFEST-96			GW	
MICROFEM				
MODFLOW				
MT3D				
Spreadsheet Analysis		x		
RESRAD				VZ/GW

n/a not applicable; VZ vadose zone; GW groundwater

A.8

Table A.2. Model Attributes of Key Projects in the Environmental Restoration Program

Model Attributes	Hanford Site-Wide Remediation Strategy	Environmental Restoration Disposal Facility	Hanford Remedial Action/Land Use EIS	200 Area Soil Remediation
Boundary Conditions				undecided
Basalt Outcrops		n/a		
No Flow	x		x	
Rattlesnake Hills Spring Discharge			x	
Cold Creek Valley		n/a		
Constant Head				
Constant Flux	Steady-state		Steady-state	
Dry Creek Valley		n/a		
Constant Head				
Constant Flux	Steady-state		Steady-state	
Yakima River		n/a		
Constant Head	Steady-state		Steady-state	
Constant Flux				
Columbia River		n/a		
Constant Head	Steady-state		Steady-state	
Constant Flux				
Local-scale Boundaries	n/a	n/a	n/a	
Natural Recharge		x	x	
Base of Model		n/a		
5 m below Water Table				
Hanford/Ringold Contact				
Top of Lower Ringold Mud Unit				
Top of Columbia River Basalts	x		x	

Table A.2. Model Attributes of Key Projects in the Environmental Restoration Program

Model Attributes	Hanford Site-Wide Remediation Strategy	Environmental Restoration Disposal Facility	Hanford Remedial Action/Land Use EIS	200 Area Soil Remediation
Hydrostratigaphic Units	2	1	1	Undecided
Hanford Formation	x			
Ringold Formation (as single unit)	x	x		
Combined Hanford and Ringold Formation			x	
Palouse Soil				
Plio-Pliestocene Unit				
Upper Ringold (Unit 4)				
Middle Ringold (Unit 5)				
Middle Ringold (Unit 6)				
Middle Ringold (Unit 7)				
Lower Ringold (Unit 8)				
Basal Ringold (Unit 9)				
Columbia River Basalt				
Contaminants Considered				
Radionuclides	x	x	x	x
Chemicals	x	x	x	x

Table A.3. Model Attributes of Key Projects in the Environmental Restoration Program

Model Attributes	Hanford Groundwater Project		Composite Analysis	Columbia River Comprehensive Impact Assessment	Canyon Disposition Initiative
	Future Water-Level Assessment	Impacts to Drinking Water Systems and Groundwater Use			
Current Status					
Work Completed					
No future work needed					
Future Revisions Needed	x	x	x		x
Work Initiated					
Work Planned and In Baseline					
Work Planned and not in Baseline				x	
Drivers					
CERCLA					x
RCRA Compliance		x			
NEPA					
DOE Guidance			Composite Analysis Guidance		
DOE Orders		x			
Facility Permitting		x			x
Emergency Response					
DNFSB			94-2		
Public Interest				x	
Purpose or Objective of Analysis					
Disposal Site Screening Analysis					
Site Performance Assessment			x		
Design and Evaluation of Remediation Strategy					
Assessment of Environmental Impacts		x	x	x	x
Evaluation of Monitoring Network and Design	x	x			x
Risk Assessment					

Table A.3. Model Attributes of Key Projects in the Environmental Restoration Program

Model Attributes	Hanford Groundwater Project		Composite Analysis	Columbia River Comprehensive Impact Assessment	Canyon Disposition Initiative
	Future Water-Level Assessment	Impacts to Drinking Water Systems and Groundwater Use			
Scope of Analysis					
Dimensionality	2-D	3-D	3-D	?	?
Model Orientation	Areal				
Flow Analysis					
Vadose Zone Flow			Transient		
Groundwater Flow	SS & Transient	SS & Transient	SS & Transient	x	x
Transport Analysis	n/a				
Vadose Zone Transport			Transient	Transient	x
Groundwater Transport		Transient	Transient	Transient	x
Geochemical Capabilities Used/Required					
Sorption		x	x	x	x
Radioactive Decay w/o chain decay		x	x	x	x
Radioactive Decay with Chain Decay			x	?	?
Scale of Analysis					
Spatial Scale	Site-wide	Site-wide	Site-wide	Site-wide	?
Time Scale	<200 yrs	<200 yrs	<1000 yrs	>10,000 yrs	?
Codes Used				?	?
VAM3DCG					
PORFLOW					
STOMP			VZ		
MEPAS					
CFEST-SC or CFEST-96	GW	GW	GW		
MICROFEM					
MODFLOW					
MT3D					
Spreadsheet Analysis					

n/a not applicable; VZ vadose zone; GW groundwater

Model Attributes	Hanford Groundwater Project		Composite Analysis	Columbia River Comprehensive Impact Assessment	Canyon Disposition Initiative
	Future Water-Level Assessment	Impacts to Drinking Water Systems and Groundwater Use			
Boundary Conditions				Undecided	Undecided
Basalt Outcrops					
No Flow	x	x	x		
Rattlesnake Hills Spring Discharge	x	x	x		
Cold Creek Valley					
Constant Head					
Constant Flux	Steady-state	Steady-state	Steady-state		
Dry Creek Valley					
Constant Head					
Constant Flux	Steady-state	Steady-state	Steady-state		
Yakima River		n/a	n/a		
Constant Head	Steady-state				
Constant Flux					
Columbia River					
Constant Head	Steady-state	Steady-state	Steady-state		
Constant Flux					
Local-scale Boundaries	n/a	n/a	n/a	n/a	
Natural Recharge	x	x	x		
Base of Model					
5 m below Water Table					
Hanford/Ringold Contact					
Top of Lower Ringold Mud Unit		x	x		
Top of Columbia River Basalts	x	x	x		

n/a not applicable; VZ vadose zone; GW groundwater

A.13

Table A.3. Model Attributes of Key Projects in the Environmental Restoration Program

Model Attributes	Hanford Groundwater Project		Composite Analysis	Columbia River Comprehensive Impact Assessment	Canyon Disposition Initiative
	Future Water-Level Assessment	Impacts to Drinking Water Systems and Groundwater Use			
Hydrostratigraphic Units Considered	1	10	10	?	?
Hanford Formation		x	x		
Ringold Formation (as single unit)					
Combined Hanford and Ringold Formation	x				
Palouse Soil		x	x		
Plio-Pliestocene Unit		x	x		
Upper Ringold (Unit 4)		x	x		
Middle Ringold (Unit 5)		x	x		
Middle Ringold (Unit 6)		x	x		
Middle Ringold (Unit 7)		x	x		
Lower Ringold (Unit 8)		x	x		
Basal Ringold (Unit 9)		x	x		
Columbia River Basalt		x	x		
Contaminants Considered					
Radionuclides		x	x	x	x
Chemicals				x	x

n/a not applicable; VZ vadose zone; GW groundwater

A.14

Table A.4. Model Attributes of Key Projects in the Waste Management and Tank Waste Remediation System Programs

Model Attributes	Waste Management					Tank Waste Remediation System			
	LLW Burial Grounds Performance Assessment		Liquid Effluents Program					TWRS Low Activity Waste Disposal Facility	
	200 East Area	200 East Area	ETF	Other Discharges	Solid Waste EIS	TWRS EIS	Hanford Tank Initiative	Interim PA	Final PA
Current Status									
Work Completed									
No future work needed									
Future Revisions Needed	x	x	x			x		x	
Work Initiated					x		x		x
Work Planned and In Baseline				x					
Work Planned and not in Baseline									
PA Maintenance	x	x							x
Drivers									
CERCLA									
RCRA Compliance							x		
NEPA					x	x	x		
DOE Orders	5820.2A	5820.2A	5400.5					5820.2A	5820.2A
Facility Permitting			x	x					
Emergency Response									
Public Interest									
Purpose or Objective of Analysis									
Disposal Site Screening Analysis								x	
Site Performance Assessment	x	x						x	x
Design and Evaluation of Remediation Strategy							x		
Assessment of Environmental Impacts			x	x	x	x	x		x
Evaluation of Monitoring Network and Design			x	x					
Risk Assessment									

n/a not applicable; VZ vadose zone; GW groundwater

Model Attributes	Waste Management					Tank Waste Remediation System			
	LLW Burial Grounds Performance Assessment		Liquid Effluents Program					TWRS Low Activity Waste Disposal Facility	
	200 East Area	200 East Area	ETF	Other Discharges	Solid Waste EIS	TWRS EIS	Hanford Tank Initiative	Interim PA	Final PA
Scope of Analysis									
Dimensionality	2-D	2-D	3-D	?	2-D	2-D	2-D	2-D	2-D
Model Orientation	X-section	X-section		?	Areal	Areal/X-sect	Areal/X-sect	Areal/X-sect	Areal/X-sect
Flow Analysis				?					
Vadose Zone Flow					Steady-state	Steady-state	Transient	SS & Trans.	SS & Trans.
Groundwater Flow	Steady-state	Steady-state	Transient	?	Steady-state	Steady-state	Steady-state	SS & Trans.	SS & Trans.
Transport Analysis									
Vadose Zone Transport				?	Transient	Transient	Transient	Transient	Transient
Groundwater Transport			Transient		Transient	Transient	Transient	Transient	Transient
Geochemical Capabilities Used/Required									
Sorption	x	x	x		x	x	x	x	x
Radioactive Decay w/o chain decay	x	x	x		x	x	x	x	x
Radioactive Decay with Chain Decay	x	x			x	x	x	x	x
Scale of Analysis									
Spatial Scale	Local	Local	Local	?	Site-wide	Site-wide	Loc/ Site-wd	Loc/ Site-wd	Loc/ Site-wd
Time Scale	<10,000 yrs	<10,000 yrs	<200 yrs	?	<10,000 yrs	<10,000 yrs	<10,000 yrs	>10,000 yrs	>10,000 yrs
Codes Used				?					
VAM2D/VAM3DCG	VZ/GW	VZ/GW				VZ/GW		GW	GW
PORFLOW							VZ/GW	VZ	VZ
STOMP					VZ				
MEPAS							VZ/GW		
CFEST-SC or CFEST-96			GW		GW				
MICROFEM									
MODFLOW									
MT3D									

Table A.4. Model Attributes of Key Projects in the Waste Management and Tank Waste Remediation System Programs

Model Attributes	LLW Burial Grounds Performance Assessment — 200 East Area	LLW Burial Grounds Performance Assessment — 200 East Area	Liquid Effluents Program — ETF	Liquid Effluents Program — Other Discharges	Solid Waste EIS	TWRS EIS	Hanford Tank Initiative	TWRS Low Activity Waste Disposal Facility — Interim PA	TWRS Low Activity Waste Disposal Facility — Final PA
Boundary Conditions				Undecided					
Basalt Outcrops	n/a	n/a							
No Flow			x		x	x	x	x	x
Rattlesnake Hills Spring Discharge					x	x	x		
Cold Creek Valley	n/a	n/a	n/a						
Constant Head									
Constant Flux					Steady-state	Steady-state	Steady-state	Steady-state	Steady-state
Dry Creek Valley	n/a	n/a	n/a						
Constant Head									
Constant Flux					Steady-state	Steady-state	Steady-state	Steady-state	Steady-state
Yakima River									
Constant Head	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Steady-state	Steady-state
Constant Flux									
Columbia River			n/a	n/a					
Constant Head	Steady-state	Steady-state			Steady-state	Steady-state	Steady-state	Steady-state	Steady-state
Constant Flux									
Local-scale Boundaries									
Constant Head	Steady-state	Steady-state						Steady-state	Transient
Constant Flux			Transient						
Natural Recharge	x	x	x			x	x	x	x
Base of Model									
5 m below Water Table	x	x							
Hanford/Ringold Contact			x						
Top of Lower Ringold Mud Unit									
Top of Columbia River Basalts			x		x	x	x	x	x

n/a not applicable; VZ vadose zone; GW groundwater

Table A.4. Model Attributes of Key Projects in the Waste Management and Tank Waste Remediation System Programs

| | Waste Management | | | | | Tank Waste Remediation System | | | |
| Model Attributes | LLW Burial Grounds Performance Assessment | | Liquid Effluents Program | | | | | TWRS Low Activity Waste Disposal Facility | |
	200 East Area	200 East Area	ETF	Other Discharges	Solid Waste EIS	TWRS EIS	Hanford Tank Initiative	Interim PA	Final PA
Hydrostratigraphic Units Considered	2	2	9	Undecided	2	2	2	2	2
Hanford Formation	x	x	x		x	x	x	x	x
Ringold Formation (as single unit)	x	x			x	x	x	x	x
Combined Hanford / Ringold Formation									
Palouse Soil			x						
Plio-Pliestocene Unit			x						
Upper Ringold (Unit 4)			x						
Middle Ringold (Unit 5)			x						
Middle Ringold (Unit 6)			x						
Middle Ringold (Unit 7)			x						
Lower Ringold (Unit 8)			x						
Basal Ringold (Unit 9)			x						
Columbia River Basalt									
Contaminants Considered									
Radionuclides	x	x	x	x	x	x	x	x	x
Chemicals					x	x	x		

n/a not applicable; VZ vadose zone; GW groundwater   A.18

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